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PHYSICS
IN
EVERYDAY LIFE

BY
WILLIAM D. HENDERSON, Ph.D.
UNIVERSITY OF MICHIGAN

LYONS AND CARNAHAN

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PREFACE

THE method employed in this text is, first, to begin each division of the subject with a discussion of some commonly occurring and familiar phenomenon, the object being to arouse the interest of the student and to provide a point of contact through the medium of his experience; second, to present in clear and simple language the physical laws and principles governing the case; and finally, to show how these governing laws and principles may be applied to the affairs of everyday life. In other words, the order of procedure is (a) interesting introductory topics, (b) discussion of laws and principles, and (c) practical applications.

It will be noted that an unusually large amount of illustrative and supplementary material is provided. It is not intended, however, that all this material shall be used in any given course. It is assumed that the teacher will select such illustrative and supplementary topics as will best meet the needs of the special interests of his community and the capacity of his class. The fundamental idea is to impress upon the student the fact that physics is not merely a formulation of abstract laws but that it is a science which touches life upon every hand.

At the close of each chapter there are given carefully graded and very thorough review exercises, the mastery of which will enable the student to meet the most exacting college or university entrance requirements.

The author wishes to acknowledge his indebtedness for permission to use the following illustrations: Fig. 194, from Kraus and Hunt's "Mineralogy" (McGraw-Hill), and Figs. 295-306 from Prof. Dayton C. Miller's "Science of Musical Sounds" (Macmillan).

W. D. HENDERSON

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**"Calamity Jane" on Meuse Front firing the last American shot
of the war**



**Steam shovel at work in a railway cut
Machines in war and peace
vi**



British tank going into action



The tractor on the farm

Machines in war and peace



PHYSICS IN EVERYDAY LIFE

CHAPTER I

MEASUREMENT OF PHYSICAL QUANTITIES

FUNDAMENTAL UNITS

1. Introductory. Science is commonly defined as classified knowledge. Botany and zoölogy, which deal with living things, are said to belong to the biological sciences; astronomy, physics, and chemistry, on the other hand, belong to the physical sciences. *Physics* treats of the related phenomena of matter and energy, and the measurement of physical quantities. Physics includes the subjects of Mechanics, Heat, Sound, Light, and Magnetism and Electricity.

Matter may be defined in a general way as anything which occupies space and has weight. Thus wood, water, and air are forms of matter, for it may be shown that all three occupy space and have weight. Electricity, heat, and light, on the other hand, are not generally considered to be forms of matter; they do not, in the ordinary sense of the term, possess weight. *Mass* is the quantity of matter which a body contains.

Energy is the capacity for doing work. Whenever anything is capable of doing work in any form whatsoever we say that it possesses energy. Thus the human body possesses energy because it is capable of doing work. Likewise the steam in an engine, the water in a mill pond, the coiled spring of a watch which has been wound, all possess energy. It should be noted that energy does not necessarily imply the doing of work, but the capacity to do work.

2. Physical Measurements. *Early concepts.* Early in the history of the race the measurement of length, volume, mass, and time became necessary in order that people might carry

on trade and other forms of commercial intercourse. The first units employed were naturally those derived from parts of the human body, and such commonly observed phenomena as occurred at regular intervals. For example, the "foot" and the "span" were quite naturally selected as the units of length, the former being a length equal to the average adult human foot, and the latter equivalent to the distance from the end of the thumb to the tip of the longest finger of the outstretched hand.

Early concepts of mass were expressed in terms of weight as measured by the muscular effort required to lift a given body. Even to the present day people frequently estimate the mass of a body by "hefting" it, that is, by lifting it and noting the amount of muscular effort put forth.

The passage of time then, as now, was recorded approximately by the seasons, the phases of the moon, and by the recurrence of day and night.

Household measurements. Before the days of "Household Economics" and "Domestic Science" practically all measurements involving household processes were made by the rule of thumb method. Even yet we are familiar with such vague and unscientific terms as a "handful of flour," a "pinch of salt," and "a few drops of oil." The use of the terms "spoonful" and "cupful" indicate a degree of improvement in the line of accuracy, but the day is at hand when, at the behest of science and economy, these common units of measurement will have to give place to more accurate and scientific terms. In factories, hospitals, and large hotels where food is prepared on a large scale, masses and volumes are measured with precision, temperatures determined accurately, and the time factor in each process is carefully controlled. And in these days when science is being extended to every phase of common life there is no valid reason why similar methods, which make for efficiency and economy, should not be applied to most, if not all, of the ordinary household processes. Suit-

able apparatus for the measurement of mass, volume, and temperature can now be procured at a small cost, and no household in which economy and health are of prime importance should be without these appliances.

Industrial processes. Modern industry owes its efficiency in no small measure to the fact that careful measurements today control processes, fix dimensions, determine proportions, and standardize products. The accurate measurement of the parts of machines or accessories makes it possible to manufacture these parts separately and to assemble them without fitting. In many industries, also, efficient operation is dependent upon measured control of heat, electric current or power. Steel should be "quenched" at a certain stage in cooling, bread should rise at a given temperature, and similar account must be made of many other processes in order to secure the best results. Properties of materials such as iron and steel, paints and oils, cement and building tile, and many other substances may be accurately determined, thus giving a means of controlling quality and establishing fixed standards. Indeed, we may well say that, in the modern world, measurement guides the processes of all industries and keeps their output up to fixed standards.

3. Fundamental Legal Standards. The fundamental units of length, volume, capacity, and mass, of the United States are those of the metric system, which was legalized by Act of Congress in 1866. The metric system was first introduced by the French about the year 1793, and has since been adopted, in whole or in part, by most of the civilized countries of the world. The meter was originally intended to be equivalent to one ten-millionth of an earth quadrant, that is, one-fourth of a great circle of the earth; and the kilogram was intended to be equivalent to the mass of one liter of pure water. As it was found impossible, however, to determine exactly these quantities, there were arbitrarily chosen as standards a meter and a kilogram which are approximately equal to the theo-

retical values determined upon by the originators of the system.

The meter and kilogram which were finally chosen as standards, and which were made of platinum, are kept in the Palace of the Archives at Paris, and are known as the "Standards of the Archives."

4. The International Metric Standards. In 1872 an International Conference of Weights and Measures was called at Paris. The object of this conference was to consider the



FIG. 1. — International Laboratory at Sèvres, near Paris, France, where the International Metric Standards are kept

question of International Standards. Thirty countries responded, the United States being among the number. At this meeting three things were accomplished: (a) An International Bureau of Weights and Measures was organized; (b) an International Laboratory, located near Paris, was established, Fig. 1; and (c) the construction of a number of prototype standards, similar to the Standards of the Archives, was authorized. As a result of this conference a number of standard meters and kilograms was constructed of an alloy

of 90 per cent platinum and 10 per cent iridium, each instrument being as nearly as possible an exact duplicate of the corresponding Standards of the Archives. That meter and that kilogram which most closely corresponded to the meter and the kilogram of the Archives were chosen as the International Standards, and were deposited in the International Laboratory, where they are now kept for reference. The remaining standards were disposed of by lot to the various countries represented, the United States drawing two meters and two kilograms, meters Nos. 21 and 27, and kilograms Nos. 4 and 20. As has already been stated these standards were brought to this country and are now kept in the Bureau of Standards at Washington.

A very good idea of the appearance of the U. S. standard meter and kilogram may be obtained from Figs. 2, 3 and 4, which are copies of actual photographs. Fig. 2 shows a longitudinal section of U. S. prototype meter No. 27, and Fig. 3 a



FIG. 2.—Section of U. S. Standard Meter

cross section of this standard meter, actual size. Fig. 4 is reproduced from a photograph of standard kilogram No. 20. The standard kilogram is cylindrical in shape, rests upon a circular base, and is enclosed within two glass bell jars as shown.

5. Two Systems of Measurement. In some countries (France, Germany, and the South American Republics), the metric system is used both for scientific and commercial pur-

poses. In the United States and Great Britain, however, two systems of units of length and mass are in common use, the metric and the English. The metric unit of length is the meter; the English unit, the yard. The metric unit of mass is the kilogram; the English unit, the pound.

It is important for the student to note that a distinction must be made be-

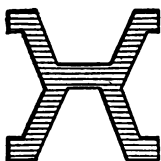


FIG. 3.—Cross section of Standard Meter, actual size

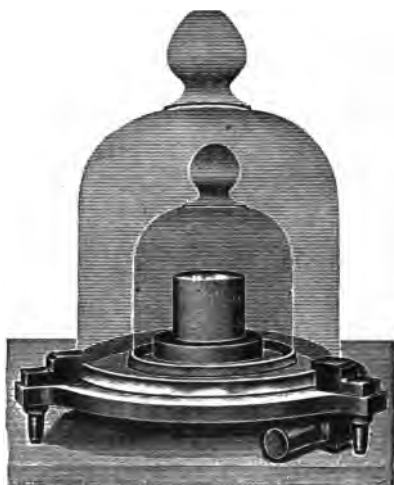


FIG. 4.—U. S. Standard Kilogram

tween the English units of the United States and those of Great Britain. Our English units, the inch, the foot, the yard, the pound, and so forth, come historically from those of England, but in actual practice today they are derived from our national metric standards at Washington. For example, the U. S. inch as defined by Act of Congress is as follows:

$$1 \text{ inch (U. S.)} = \frac{1}{39.37} \text{ of a meter.}$$

In Great Britain, on the other hand, the inch is defined as $1/36$ of a standard British yard. The standard British yard and pound, together with the metric standards of that country, are kept at the office of the Exchequer in London.

The U. S. inch is slightly longer than the British inch, as shown by the following:

$$1 \text{ meter} = 39.37 \text{ U. S. inches} = 39.37079 \text{ British inches.}$$

Since the English units of this country are defined by law in terms of the metric system, we shall consider first the metric units of length, volume, capacity, and mass, after which we shall define the corresponding English (U. S.) equivalents.

6. Metric Units of Length. The metric unit of *length* is the meter. A *meter* is the distance between two cross marks on a platinum-iridium bar which is kept in the Bureau of Standards at Washington, the measurement being made at 0° C. In designating fractions of the meter we use the Latin prefixes, deci, centi, milli; multiples, the Greek prefixes, deka, hecto, kilo. The divisions and multiples of the meter are:

<i>Fractions</i>		<i>Multiples</i>	
1 decimeter (dm)	= 1/10 meter	1 dekameter (dkm)	= 10 meters
1 centimeter (cm)	= 1/100 meter	1 hectometer (hm)	= 100 meters
1 millimeter (mm)	= 1/1000 meter	1 kilometer (km)	= 1000 meters

7. Metric Units of Volume and Capacity. The metric unit of *volume* is the cubic meter (m^3). The fractional units of volume are the cubic decimeter (dm^3) and the cubic centimeter (cm^3).

The metric unit of *capacity* is the liter. A *liter* is the volume of one kilogram of air-free distilled water at 4° C. The reason for defining the liter in terms of the volume of a kilogram of air-free distilled water at 4° C, instead of defining it directly as 1000 cm^3 is because of the convenience in calibrating glass flasks and similar vessels.

$$1 \text{ liter} = 1000 \text{ cc} = 1000.027 \text{ cm}^3$$

$$1 \text{ cc} = 1/1000 \text{ liter} = 1 \text{ milliliter (ml)}$$

Since a kilogram of water at 4° C has a volume which is very nearly equal to a cubic decimeter, a liter will be considered as equivalent to 1000 cm^3 , unless specified to the contrary.

Bureau of Standards Circular No. 9 contains the following statement: "In all volumetric work the unit of volume employed is the milliliter and not the cubic centimeter, but in

this country it is ordinarily designated by the letters *cc.* This designation is so firmly established both in trade and in laboratory practice that it is for the present retained in this circular, though in strictness the abbreviation *ml* should be used. It is hoped the correct usage may soon replace the present inexact use of the term *cc.*"

8. Metric Units of Mass. The U. S. standard of *mass* is the kilogram. A *kilogram* is a mass equivalent to the National Standard Kilogram. A *gram* is 1/1000 of a kilogram. For all practical purposes a gram may be considered as equivalent to the mass of a cubic centimeter of air-free distilled water. The divisions of the kilogram and gram are given in the following tables:

1 gram (g)	= 1/1000 kilogram (kg)
1 decigram (dg)	= 1/10 gram
1 centigram (cg)	= 1/100 gram
1 milligram (mg)	= 1/1000 gram

9. Unit of Time. The unit of *time* is the second. A *second* is 1/86,400 of a mean solar day. A *solar day* is the interval between two successive passages of the sun across a given meridian. Solar days vary in length throughout the year. A *mean solar day* is the average length of all the solar days taken throughout the year. The time recorded by watches and clocks is expressed in mean solar time.

10. Metric Units and U. S. English Equivalents. The following table contains the metric units of length, capacity, and mass, and their legal English equivalents. In Fig. 5, there is shown graphically the relation between the centimeter and the inch in linear and square measure.

<i>Metric Units</i>	<i>English Equivalents</i>
1 meter	= 39.37 inches
1 liter	= 1.0567 quarts (liquid measure)
1 liter	= 0.908 quarts (dry measure)
1 kilogram	= 2.204622 pounds
1 gram	= 15.432 grains

11. U. S. English Units and Metric Equivalents. The following table contains the U. S. English units of length,

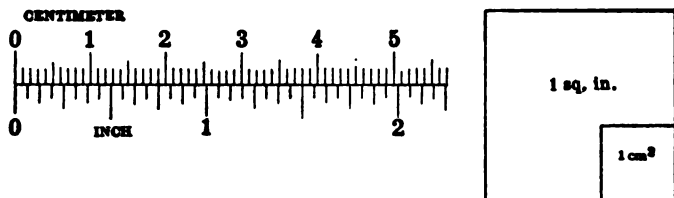


FIG. 5. — Comparison of centimeter and inch



FIG. 6. — Comparison of capacities of dry quart and of liquid quart. Dry commodities are often illegally sold by the smaller liquid measure. The beans on the table show the resulting shortage on a quart so measured.

capacity, and mass, together with certain recently adopted standards.

U. S. English Units

1 inch	= 1/39.37 meter = 2.54 centimeters
1 quart (L.M.)	= 946.333 cubic centimeters
1 quart (D.M.)	= 1101.2 cubic centimeters
1 pound	= 1/2.204622 kilogram = 453.592 grams
1 gallon	= 231 cubic inches
1 bushel	= 2150.42 cubic inches
1 standard barrel	= 7056 cubic inches

It will be noted from the foregoing values that the capacity of a quart, liquid measure, is 946.333 cm³, while that of a quart, dry measure, is 1101.2 cm³; that is, a "liquid" quart is less in volume than a "dry" quart. Dry commodities are frequently sold by the smaller liquid measure. The beans on the table, Fig. 6, show the resulting shortage on a quart of commodity so measured.



Fig. 7.—A "bushel basket" which contains less than the legal requirement of 2150.42 cubic inches

Also, a bushel of legal standard capacity contains 2150.42 cubic in. The so-called "bushel basket" shown in Fig. 7, contains a false bottom, thus making its capacity considerably less than that required by law.

According to the rules of the U. S. Mint, the following pieces of money, as legalized by Act of Congress, are coined in terms of the metric units of mass. The mass of a

5 cent piece (nickel)	= 5.0 grams
10 cent piece (dime)	= 2.5 grams
25 cent piece (quarter)	= 6.25 grams
50 cent piece (half dollar)	= 12.5 grams

The fineness of gold and the weight of precious stones are measured in terms of the "karat" and the "carat" respectively.

1 karat (fineness of gold) = $1/24$ by weight of pure gold

1 carat (in precious stones) = 200 milligrams

For example, a ring of 18 karats fineness contains $18/24$ of pure gold; 24 karats fine signifies pure gold. On the other hand, a 5-carat diamond is one that weighs 5×200 milligrams = 1 gram.

12. Spelling and Abbreviation of Units. In Circular No. 47, issued July 1, 1914, the National Bureau of Standards offers certain recommendations with reference to the spelling and abbreviations of units. Among the rules adopted by the Bureau are the following:

1. "The period is omitted after abbreviations of metric units, while it is used after those of the customary system." For example, we should write *cm* for centimeter, *mm* for millimeter, *m* for meter, and so on; in the case of units of the English system, however, we write *ft.* for foot, *lb.* for pound, *cu. ft.* for cubic foot, and so forth.

2. "The exponents ² and ³ are used to signify area and volume respectively in the case of the metric units, instead of the longer prefixes *sq. cm.*, or *cu. cm.*" In accordance with this rule, therefore, we should write cm^2 for square centimeter, and cm^3 for cubic centimeter. It should be noted in this connection, however, that it is customary in chemical practice, as well as in certain texts in physics, to employ the symbol *cc* to designate the milliliter (*ml*).

3. "The use of the same abbreviation for both singular and plural is recommended. Thus, *cm* may stand for centimeter or centimeters."

13. F. P. S. and C. G. S. Systems of Measurement. When in the English system we use the foot as the unit of length, the pound as the unit of mass, and the second as the unit of time, we speak of the system of units thus employed as the f. p. s. or foot-pound-second system. Likewise, when in the metric system we use the centimeter as the unit of length,

the gram as the unit of mass, and the second as the unit of time, we speak of it as the centimeter-gram-second or c. g. s. system of measurement.

MEASURING INSTRUMENTS

14. Instruments for Measuring Length. For ordinary measurements of length the foot rule, the yard stick, and the meter stick are employed. In the measurement of land distances and areas, surveyors use a specially calibrated steel tape. When it is desired to measure distances having a magnitude less than that of the least scale part of the main scale a device called a vernier is employed. The *vernier*, Fig. 8, is an accessory scale which slides upon the main scale.

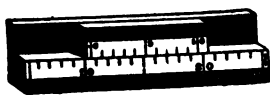


FIG. 8. — Vernier

The parts of the vernier are usually so calibrated that 10 scale parts correspond to 9 scale parts of the main scale, thus enabling the observer

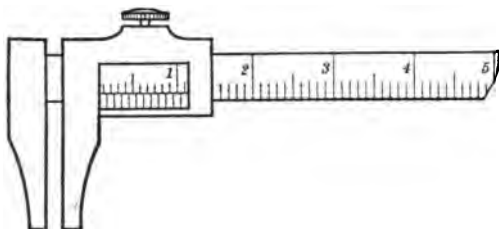


FIG. 9. — Vernier caliper

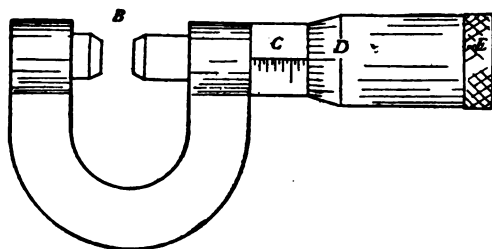


FIG. 10. — Micrometer gauge

The least reading of the main scale of the vernier caliper shown in Fig. 9 is one millimeter (1 mm). The number of scale parts on the vernier (sliding scale) is 10; such an instrument is therefore capable of giving readings directly to $1/10$ mm.

to read to tenths of the least reading on the main scale. In a like manner a vernier may be calibrated to give readings which are equivalent to hundredths of the smallest reading of the primary scale.

15. Vernier Caliper.

In order to measure accurately relatively small objects, such as rods, bolts, and so forth, the vernier caliper is employed. The maximum spread of the jaws of this instrument ranges usually from 4 to 5 centimeters to 5 or 6 inches.

16. Micrometer Gauge. In the measurement of very short lengths, such as the diameter of a wire, a micrometer gauge is used. In this instrument, Fig. 10, the vernier scale is etched on the circular milled screw, *D*. Micrometer gauges usually give readings to $1/100$ mm.

17. Wire Gauge. The size of a wire is usually designated by its gauge number. To determine the diameter of a given sample of wire, a wire gauge, Fig. 11, may be used to advantage. In order to find the diameter in millimeters corresponding to a number of the gauge, it is necessary to refer to a wire gauge table such as is given on page 14. For example, a given wire which just fits hole No. 14 in the gauge has a diameter of 1.628 mm; and in like manner a wire gauge No. 30 has a diameter of 0.255 mm, as shown by Table I, in which diameters are given in millimeters and in mils. A *mil* is $1/1000$ of an inch.



FIG. 11

18. Measurement of Angles. The *protractor* is used in the measurement of angles. This instrument, Fig. 12, consists of a circle, graduated in degrees. To measure the angle *A* for example, Fig. 13, place the protractor with its base lying on the line *AB*, and its center on the

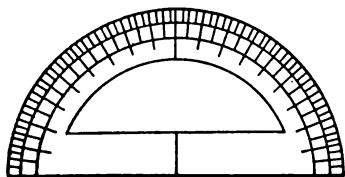


FIG. 12

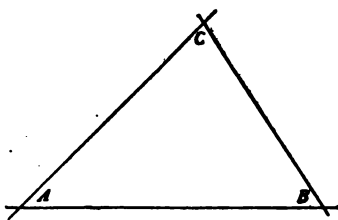


FIG. 13

Protractor and triangle

point *A*. The angle *BAC* may now be read off directly from the instrument. In reading the angles we estimate values to tenths of the smallest divisions of the scale. We proceed in the same manner with the angles *B* and *C*.

TABLE I

WIRE GAUGE VALUES, AMERICAN (B. & S.)

Gauge No.	Diam. in mm	Diam. in mils	Gauge No.	Diam. in mm	Diam. in mils
0000	11.684	460.00	19	.899	35.39
000	10.405	409.64	20	.812	31.96
00	9.266	364.80	21	.723	28.46
0	8.254	324.95	22	.644	25.35
1	7.348	289.30	23	.573	22.57
2	6.544	257.63	24	.511	20.10
3	5.827	229.42	25	.455	17.90
4	5.189	204.31	26	.405	15.94
5	4.621	181.94	27	.361	14.19
6	4.115	162.02	28	.321	12.64
7	3.665	144.28	29	.286	11.26
8	3.264	128.49	30	.255	10.03
9	2.907	114.43	31	.227	8.93
10	2.588	101.89	32	.202	7.95
11	2.305	90.74	33	.180	7.08
12	2.053	80.81	34	.160	6.30
13	1.828	71.96	35	.143	5.61
14	1.628	64.01	36	.127	5.00
15	1.450	57.07	37	.113	4.45
16	1.291	50.82	38	.101	3.96
17	1.150	45.26	39	.090	3.53
18	1.024	40.30	40	.080	3.14

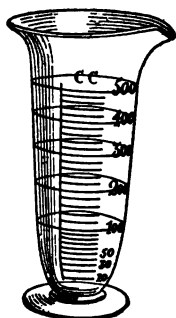


FIG. 14.—Graduate

19. Measurement of Volume. Liquids. When it is necessary to measure a liquid with a greater degree of accuracy than that which is possible by the usual household pint and quart measures, a graduated vessel, or as it is commonly called a "graduate," Fig. 14, is necessary. Graduates are frequently calibrated so as to give readings in both cubic centimeters and the English fluid measure.

Solids. The volume of a solid having an irregular outline may be accurately determined by immersing the body in a graduated vessel, Fig. 15, containing a liquid, as water. The difference between the initial level of the liquid in the vessel and the final level is a measure of the volume of the solid.

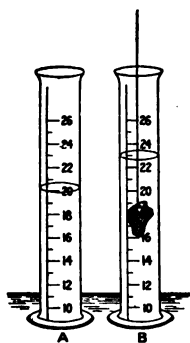
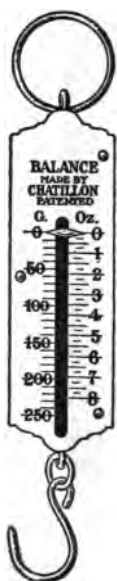


FIG. 15

FIG. 16
Spring balance

20. Measurement of Mass. *Commercial and household apparatus.* In ordinary commercial transactions, in which roughly approximate values are required, such as in the mass measurements of coal, hay, salt, and so forth, large trade scales are now used. For smaller masses the spring balance, Fig. 16, is a convenient instrument. A reasonably accurate and very convenient household balance is shown in Fig. 17.



FIG. 17. — Household balance

Laboratory balances. In the laboratory, fairly accurate values may be determined by means of a beam balance, as illustrated in Fig. 18.

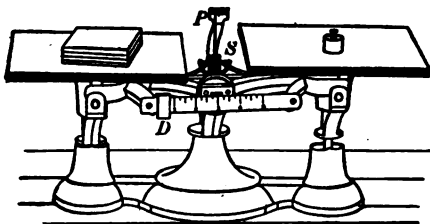


FIG. 18. — Laboratory beam balance



FIG. 19. — Analytical balance

Analytical balance. Very accurate determinations of mass require the use of an analytical balance, one type of which is shown in Fig. 19. A set of standard gram weights, ranging in value from 100 grams to a gram, designed for use with such a balance, is shown in Fig. 20.

21. Measure of Time. Very early in human history methods were devised for measuring the passage of time, as illustrated by the sun-dial, the hour glass and the water clock. The modern watch and clock furnish excellent examples of manufacturing skill in the production of relatively accurate and at the same time very cheap recording instruments.



FIG. 20. — Set of standard gram weights

For railroad engineers, signal officers, and other public officials it is extremely important that timepieces be carefully adjusted and frequently tested. The chronometer is a specially jeweled and very carefully adjusted clock, usually put up in box form, which is used as a standard of reference. In modern practice time signals are sent out once a day by wireless from the Observatory at Washington. A receiving set suitable for picking up these time signals has been installed in recent years by nearly all first-class dealers in timepieces.

MEASUREMENT TABLES

TABLE II

SOME IMPORTANT EQUIVALENTS AND EQUATIONS

NOTE.—The approximate values employed in ordinary computations are given in parenthesis.

$$\pi = 3.1416; \pi^2 = 9.8696 = (9.87); \sqrt{\pi} = 1.7724; \log \pi = 0.49715.$$

$$\text{Conversion factor between common and natural logs} = 2.30258 = (2.3).$$

$$\log_{10} n = \log_e n / 2.3; \log_e n = \log_{10} n \times 2.3.$$

$$\text{One radian} = 57^\circ.296 = (57^\circ.3); 1^\circ = 0.01745 \text{ radian.}$$

$$\sin 0^\circ = 0.0$$

$$\cos 0^\circ = 1.0$$

$$\sin 30^\circ = 0.5$$

$$\cos 30^\circ = 0.866$$

$$\sin 45^\circ = 0.707$$

$$\cos 45^\circ = 0.707$$

$$\sin 60^\circ = 0.866$$

$$\cos 60^\circ = 0.5$$

$$\sin 90^\circ = 1.0$$

$$\cos 90^\circ = 0.0$$

Circle: *circumference* = $2\pi r$; *area* = πr^2 .

Cylinder: *lateral area* = $2\pi rh$; *volume* = $\pi r^2 h$.

Cone: *lateral area* = $\frac{1}{2}$ (circumference $\times$ slant height); *volume* = $\frac{1}{3}$ (area base $\times$ height).

Sphere: *area* = $4\pi r^2$; *volume* = $\frac{4}{3}\pi r^3$.

Pressure of one atmosphere = 76 cm mercury = 30 in. mercury = 1033.3 g per cm^2 = 1,012,634 dynes per cm^2 = 14.7 lb. per in^2 .

Mass of 1 cm^3 of pure water at 4°C = 1 gram (very nearly).

Mass of 1 cu. ft. of pure water at 4°C = 62.3565 lb. = (62.4 lb.).

Mass of 1 gallon of pure water at 4°C = 8.33585 lb. = (8.3 lb.).

TABLE III

CONVERSION FACTORS

<i>Metric to English</i>		<i>English to Metric</i>	
1 kilometer	= 0.62137 mi.	1 mile	= 1.60935 km
1 meter	= 0.0006214 mi.	1 mile	= 1609.347 m
1 meter	= 3.28083 ft.	1 foot	= 0.3048 m
1 centimeter	= 0.3937 in.	1 inch	= 2.54 cm
1 liter	= 0.03532 cu. ft.	1 cubic foot	= 28.31701 l
1 liter	= 0.26417 gal.	1 gallon	= 3.78543 l
1 kilogram	= 2.2046 lb.	1 pound	= 0.45359 kg
1 gram	= 15.432 gr.	1 grain	= 0.064800 g

TABLE IV

LENGTH

12 inches	= 1 foot	100 links	= 1 chain
3 feet	= 1 yard	80 chains	= 1 mile
16.5 feet	= 1 rod	1000 mils	= 1 inch
320 rods	= 1 statute mile	4 inches	= 1 hand
3 statute miles	= 1 league	9 inches	= 1 span
1 statute mile	= 5280 feet	6 feet	= 1 fathom
1 nautical mile	= 6080 feet	40 yards	= 1 bolt (cloth)
7.92 inches	= 1 link (surveyor's measure)	40 rods	= 1 furlong

TABLE V

AREA AND VOLUME

144 square inches = 1 square foot	36 square miles = 1 township
9 square feet = 1 square yard	1728 cubic inches = 1 cubic foot
30¼ square yards = 1 square rod	27 cubic feet = 1 cubic yard
160 square rods = 1 acre	144 cubic inches = 1 board foot
640 acres = 1 square mile	128 cubic feet = 1 cord

TABLE VI

CAPACITY

<i>Dry Measure</i>			<i>Liquid Measure</i>
2 pints	= 1 quart	4 gills	= 1 pint
8 quarts	= 1 peck	2 pints	= 1 quart
4 pecks	= 1 bushel	4 quarts	= 1 gallon
1 bushel	= 2150.42 cu. in.	31½ gallons	= 1 barrel
1 barrel (fruit and vegetables) = 7056 cubic inches.		2 barrels	= 1 hogshead

Apothecaries' Fluid Measure

60 minims	= 1 fluid dram
8 drams	= 1 fluid ounce
16 fluid ounces	= 1 fluid pint
8 pints	= 1 fluid quart

TABLE VII

MASS

<i>Apothecaries' Weight</i>			<i>Troy Weight</i>
20 grains	= 1 scruple	24 grains	= 1 pennyweight
3 scruples	= 1 dram	20 pennyweights	= 1 ounce
8 drams	= 1 ounce	12 ounces	= 1 pound
12 ounces	= 1 pound		

Avoirdupois Weight

1 grain	= 0.0648 grams
437.5 grains	= 1 ounce
16 ounces	= 1 pound
1 pound	= 7000 grains
2000 pounds	= 1 short ton
2240 pounds	= 1 long ton

TABLE VIII

<i>Time</i>	
60 seconds	= 1 minute
60 minutes	= 1 hour
24 hours	= 1 day
7 days	= 1 week
365 days	= 1 year
366 days	= 1 leap year

TABLE IX

<i>Circular Measure</i>	
60 seconds	= 1 minute
60 minutes	= 1 degree
90 degrees	= 1 quadrant
4 quadrants	= 1 circle or circumference

REVIEW EXERCISES

1. Define: meter, kilometer, decimeter, centimeter, millimeter; inch, foot, yard.
2. During the war, the American soldiers in France (where only metric units are used) were instructed to consider a kilometer as equivalent to $\frac{3}{5}$ of a mile. In translating 20 kilometers into miles by the use of this ratio ($\frac{3}{5}$) what actual error was made?
3. Measure the length of this page and express your results in (a) centimeters, (b) inches.
4. An irregular piece of metal was immersed in water contained in a vessel graduated in cubic centimeters, Fig. 15. The initial reading of the liquid was 20 and the final reading 22.8. Find the volume of the metal in (a) cubic centimeters, (b) cubic inches.
5. Define: liter, milliliter; give the English equivalent of the liter in quarts, (a) liquid measure, (b) dry measure.
6. Define: kilogram, gram, decigram, centigram, milligram.
7. In an avoirdupois pound there are how many grains? grams?
8. In certain states the legal width of the country highway is 4 rods. This is equivalent to how many feet? meters?
9. At the 1912 Olympiad held at Stockholm, Sweden, the "100-meter dash" was won in the record time of 10.6 sec. At this rate find the average speed of the runner in (a) feet per second, (b) miles per hour.
10. The great cannon used by the Germans in the reduction of the Belgian forts were known as "42-centimeter guns." Find the diameter of the bore of these guns, in inches.
11. The radius of a hollow sphere is 1 ft. 8 in. Find (a) its area in square inches; (b) its volume in cubic inches.
12. Find the capacity of the sphere (problem 11) in (a) quarts; (b) liters.
13. Find the weight in pounds of \$10 in (a) nickels; (b) dimes; (c) quarters.

MECHANICS

CHAPTER II

MECHANICS OF SOLIDS

MOTION, VELOCITY, ACCELERATION

22. Introductory. Among the earliest experiences of life are those which are associated with pushes and pulls upon objects, and the resulting motions of these objects. In early childhood we are undoubtedly interested in the object itself, as a brightly colored ball, but a little later on this interest is transferred, in a large measure at least, to the motions which may be imparted to the ball. As experience ripens, we soon learn that in the great world about us there are innumerable pushes and pulls, and as a consequence a great variety of motions, other than those in which we personally take part.

Subjective
Force

Forces of nature. Nature is the name given to the world which we see around us—the sky, the rivers, the hills, the sunshine. We speak of the forces generated by the heat of the sun, those manifested in the waterfall, the bursting force of frost, and so forth, as the forces of nature. We see these forces operating everywhere about us. The hills are washed down, rocks are broken into tiny fragments, day follows night, summer follows winter. Changes due to the forces of nature are constantly going on, yet man has learned by experience that these changes do not “just happen”; they take place in a perfectly definite and orderly manner, in accordance with what are called the laws of nature.

Phenomenon, theory, law. A natural phenomenon is anything occurring in nature. The rising of smoke, the falling of rain, the sound of a whistle, the flying of a kite are all examples of natural phenomena.

A *theory* is a reason put forth to explain phenomena. Thus, in order to explain the motions of the heavenly bodies, we assume that every particle of matter in the universe attracts every other particle. This is called the theory of gravitation.

A *law* is a definite statement regarding physical phenomena, and is capable of being verified by experiment. An experiment is a question put to nature. All experimentation is based on the assumption of the constancy of nature; that is, we assume that under the same conditions nature always acts in the same manner.

23. Mechanics. The term mechanics, as originally used, referred to the study of machines. It has, however, come to have a much wider meaning, referring in a general way to the effect of forces on bodies. The force exerted by a locomotive, that exerted in the batting of a ball, the flying of a kite, the sailing of a boat, are all illustrations of the principles of mechanics.

24. Force. When we push or pull a body we exert force upon it, and the body tends to move. *Force* is that which produces or tends to produce motion. A book lying on a table exerts a force upon the table. In this case no motion is produced; the force tends to produce motion. A horse pulling a cart exerts force upon the cart, producing motion. The relation between force and motion is very well illustrated in the playing of a game of ball. The pitcher exerts force upon the ball, producing motion; the batter exerts force upon the ball, changing its motion; the catcher exerts force in destroying its motion.

The student should note here carefully that whenever we speak of a force we always think of two bodies, one as acting and the other as being acted upon. A horse pulls a load and the load resists (pulls back on) the horse; a book lying upon the table exerts a downward force on the table, and the table, on the other hand, exerts an upward force upon the book.

25. Rest and Motion Relative Terms. When a body changes its position with reference to a fixed point, it is said to be in motion. Rest and motion are purely relative terms; that is to say, a body may be at rest with reference to one object and in motion with reference to another. For example, a person sitting quietly in a moving car is at rest with respect to his seat, but in motion with respect to objects outside.

EXERCISES. 1. (a) If the hand be clenched and moved about, are the fingers at rest or in motion with reference to each other? (b) Are they at rest or in motion with reference to the body?

2. Consider the wheel of a carriage in motion. (a) Are the spokes at rest or in motion with respect to each other? (b) Are they at rest or in motion with respect to the earth?

3. Give another example of a body that is at rest in its relation to one object and in motion in relation to another.

26. Kinds of Motion. Motion may be classified with reference to direction as (a) rectilinear or straight-line motion, and (b) curvilinear or curved-line motion. Motion may also be classified with reference to rate as (c) uniform motion, and (d) accelerated motion. When a body travels over equal spaces in equal intervals of time, its motion is uniform; when it travels over unequal spaces in equal intervals of time its motion is accelerated. There is probably no such thing in the universe as an example of absolutely uniform motion, since all bodies in moving change in some degree their rate. We can, however, imagine such a thing as uniform motion, or we may find examples of motion which are approximately uniform.

EXERCISE. 4. Classify, with reference to direction and rate, the following motions: (a) The motion of the piston of a steam engine; (b) the hand of a clock; (c) a point on the circumference of the flywheel of an engine; (d) the rotation of the earth on its axis.

27. Velocity and Speed. *Velocity* is the rate of motion per unit of time. Velocity is usually expressed in miles per hour, feet per second, or centimeters per second. The term velocity, when used in a strictly scientific sense, refers to the rate of

motion of a body in a definite direction; *speed*, on the other hand, refers to the rate of motion without reference to direction.

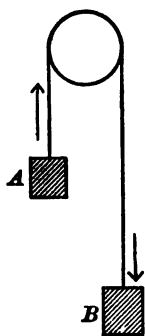


Fig. 21

Two bodies may have equal speeds, but quite different velocities. For example, suppose that two bodies *A* and *B*, Fig. 21, are connected by a flexible cord which passes over a pulley. *B* being heavier than *A*, moves downward, while *A* moves upward. The speed of *A* is the same as that of *B*; the velocity of *A*, however, is different from that of *B*, because the velocity of *B* is directed downward, while the velocity of *A* is directed upward. Strictly speaking, if we wish to describe completely the velocity of a body we have to tell three things about it, namely (a) its magnitude, (b) its direction, and (c) its sense. To

illustrate, let us suppose that the speed of *A* is 20 centimeters per second. The speed of *B*, then, is also 20 centimeters per second. The velocity of *B*, on the other hand, is described as follows: magnitude, 20 centimeters per second; direction, vertical; sense, downward. The velocity of *A* is in magnitude 20 centimeters per second; direction, vertical; sense, upward.

The *mean* or *average velocity* of a body is found by dividing the space passed over by the time.

EXERCISES. 5. The block *C*, Fig. 22, is drawn along the smooth surface of the table by means of a weight *D*, which is assumed to move downward at the uniform rate of 30 centimeters per second. (a) Describe, with reference to magnitude, direction, and sense the velocities of *C* and *D*. (b) How does the speed of *C* compare with that of *D*?

6. If a train runs 120 miles in 4 hours, what will be its average velocity in (a) miles per hour? (b) feet per hour? (c) feet per second?

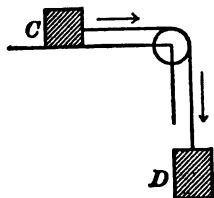


Fig. 22

28. The Force of Gravity. Daily experience teaches us that all bodies tend to fall to the earth. A piece of chalk held

in the fingers is at rest; if released it at once falls to the floor. Its condition of motion is changed. Now when the motion of a body is changed, we say that a force has acted upon it. The force by which bodies are attracted to the earth is called the *force of gravity*. The apple falls from the tree to the earth because of the force of gravity; rain falls from the clouds, rivers run to the sea, bodies everywhere tend to fall because of the constant pull exerted by the force of gravity.

The *weight* of a body is the force by which it is attracted to the earth. The weight of a body depends upon two factors (a) the quantity of matter which it contains (its mass) and (b) its position with respect to the earth. Thus, for example, for a given place on the earth's surface, a whole brick weighs more than half a brick, because the first has more mass than the second. Also, a brick at the surface of the earth weighs more than if taken some distance above the surface because the force of gravity is greater at the surface than above it.

The student should bear in mind that *weight is a force*, directed toward the center of the earth. All force is not weight, however. A force may be exerted in any direction whatsoever; weight, on the other hand, is a force due to the attraction of the earth (gravity), and is always directed toward the center of the earth.

29. Acceleration. When the velocity of a body increases or decreases its motion is said to be accelerated. *Acceleration* is the change of velocity per unit of time. If there is an increase of velocity per unit of time, the acceleration is called positive; if a decrease, negative. The symbol for acceleration which is in general use is a . Velocity is expressed in units per second; acceleration, in units per second per second. Thus, when we say that a body has an acceleration of 10 centimeters per second per second, we mean that its velocity has increased or decreased by 10 centimeters per second in one second.

Illustrations of accelerated motion are seen in the starting of a railway train or a street car from rest, the motion of a sled

or a toboggan down an incline, the rolling of a marble down an inclined plane, and in the free fall of bodies.

EXERCISES. 7. A sled starting from rest runs down hill. Its initial velocity is zero; its velocity at the end of the 1st second is 6 ft. per second; at the end of the 2d second, 12 ft. per second; at the end of the 3d second, 18 ft. per second, and so on. (a) What is the increase in velocity per second? (b) The positive acceleration?

8. A stone is thrown upward with an initial velocity of 2940 cm per second. Its velocity at the end of the 1st second is 1960 cm per second; at the end of the 2d second, 980 cm per second, and so on. (a) What is the decrease in velocity per second? (b) The negative acceleration? (c) How long will it continue to rise? (d) In how many seconds after leaving the hand will it strike the ground?

9. A ball rolling down an incline makes a gain in velocity of 20 cm in 4 seconds. What is the acceleration?

30. Falling Bodies. Whenever a force acts upon a body it always tends to produce motion. A stone dropped from the hand falls to the earth with an accelerated motion due to the force of gravity. If it were not for the friction of the air all bodies would fall with equal velocities. If a feather and a coin, for example, be dropped from a given height, it will be observed that the coin will reach the ground first. If, however, the feather and coin be placed in a long tube and the air be exhausted by means of an air pump, it will be found that both fall with the same velocity, showing that in a vacuum all bodies fall with equal velocities.



Galileo

Galileo (1564-1642), an Italian physicist, was the first to infer the truth of this statement. He had been taught that bodies fall with "velocities proportional to their weights." In order to test the truth or falsity of this statement he dropped bodies of different size and materials from the top of the Leaning Tower of Pisa. He found

that even very light bodies like paper fall with velocities which approached more and more nearly those of heavy bodies the more compactly they were wadded together. From these experiments he contended that all bodies, even the lightest, would fall at the same rate if it were not for the resistance of the air.

The acceleration imparted to a freely falling body by the force of gravity is represented by the symbol g . The numerical value of this acceleration due to gravity is approximately as follows:

$$g = 32 \text{ ft. per sec. per sec.} = 980 \text{ cm per sec. per sec.}$$

This means that if a body starts from rest and falls freely under the influence of gravity it will have at the end of the 1st second a velocity of 32 feet per second; at the end of the 2d second, 64 feet per second; at the end of the 3d second, 96 feet per second, and so on. Or, if this be expressed in metric units, its velocity at the end of the 1st second will be 980 centimeters per second; at the end of the 2d second, 1960 centimeters per second, and so on.

The values of g given above are those which are usually used in making calculations involving the acceleration due to gravity. Since the force with which the earth attracts a unit of mass differs slightly from place to place, it follows that the value of g will be somewhat different for different places, as explained in the table which follows.

The student should bear in mind that the symbol g does not stand for gravity but for the acceleration due to gravity.

TABLE X

VALUES OF G IN CM PER SECOND, PER SECOND

Boston, Mass.....	980.38	Washington, D. C.....	980.10
Ithaca, N. Y.....	980.29	Cincinnati, O.....	979.99
Chicago, Ill.....	980.26	Charlottesville, Va.....	979.92
Cleveland, O.....	980.23	Denver, Col.....	979.60
Philadelphia, Pa.....	980.18	Pike's Peak, Col.....	978.94

31. Laws of Acceleration. Let us consider the case of a body falling freely under the force of gravity. In studying accelerated motion three things should be noted. (a) The acceleration of the body; (b) its velocity at the end of any given period; (c) the space passed over during a given period. We shall take these points up in order, assuming for convenience that the acceleration g is 32 feet per second per second.

Velocity. Starting from rest the body, which is assumed to fall without friction, will have at the end of the first second a velocity of 32 feet per second. Since its gain in velocity (acceleration) per second is 32 feet per second, the body will have at the end of the 2d second a velocity of 64 feet per second; at the end of the 3d second, 96 feet per second, and so on. It is evident that the velocity at the end of any given number of seconds may be found by simply multiplying the gain per second (acceleration) by the time (number of seconds).

Space passed over. We now desire to find the space passed over in a given time (t). Since the motion is accelerated, it is necessary first to find the average velocity for the time t . The average velocity for any interval or number of intervals may be determined by taking one-half the sum of the velocities at the beginning and at the end of the interval; that is,

$$\text{Average velocity} = \frac{\text{Vel. at beginning} + \text{Vel. at end}}{2}$$

Thus, the average velocity for the 1st second is $\frac{0+32}{2} = 16$ feet

per second; for the 2d second, $\frac{32+64}{2} = 48$; for the 3d second,

$\frac{64+96}{2} = 80$, and so on. In a like manner we may find the aver-

age velocity for any number of seconds, as, for example, the first 3 seconds, thus, $\frac{0+96}{2} = 48$ feet per second.

Now, the space passed over during any interval or number of intervals is equal to the *average velocity multiplied by the*

time. Thus, for the 1st second, the average velocity is 16 feet per second and the time is 1 second, therefore, the space passed over during this second is 16 feet; for the 2d second the average velocity is 48 and the time 1, hence the space passed over is 48 feet; for the 3d second the average velocity is 80, and hence space passed over is 80 feet. Likewise since the average velocity for the first 3 seconds is 48 feet per second, and the time is 3 seconds, the total space passed over during this interval is $48 \times 3 = 144$ feet, and so on for any interval we may choose.

These facts may be given in tabular form as in the following outline:

Time	Velocity	Space per second	Total space passed over
Beginning of time.....	$V_0 = 0$	0.....	0
End of 1st second.....	$V_1 = 32$	16.....	16
End of 2d second.....	$V_2 = 64$	48.....	64
End of 3d second.....	$V_3 = 96$	80.....	144
End of 4th second.....	$V_4 = ?$	?.....	?
End of 5th second.....	$V_5 = ?$	?.....	?
End of 10th second.....	$V_{10} = ?$	?.....	?

EXERCISES. 10. Referring to the outline above, find the velocity at the end of the 4th second. The 5th second. The 10th second.

11. What is the average velocity during the 4th second? The 5th second? The 10th second?

12. What is the average velocity during the first 4 seconds? The first 5 seconds? The first 10 seconds?

13. What is the space passed over during the 4th second? The 5th second? The 10th second?—

14. What is the space passed over during the first 4 seconds? The first 5 seconds? The first 10 seconds?

15. What is the average velocity for the interval (3 seconds) included between the end of the 1st second and the end of the 4th second? What space is passed over during this interval?

32. Summary. The facts brought out in the preceding topic with reference to the accelerated motion of a body starting from rest may conveniently be summarized in the following manner. It is evident that the velocity of a body having uni-

formly accelerated motion may be determined at the end of any interval by simply adding the acceleration to the velocity at the end of the preceding interval. Since, however, the acceleration is constant, the most convenient way of finding the velocity at the end of any interval is to multiply the acceleration by the time; that is,

$$\begin{aligned}\text{velocity} &= \text{acceleration} \times \text{time} \\ v &= at\end{aligned}$$

If now, we desire to compute the space passed over by a body starting from rest, that is, having an initial velocity equal to 0, and having a velocity at the end of t seconds equal to at , we may write

$$\text{average velocity} = \frac{0+at}{2}$$

And since the space passed over is equal to the average velocity multiplied by the time,

$$\begin{aligned}\text{space} &= \text{average velocity} \times \text{time} \\ s &= \left(\frac{0+at}{2}\right) \times t = \frac{1}{2}at^2\end{aligned}$$

In the case of acceleration due to gravity our equations become

$$\begin{aligned}v &= gt \\ s &= \frac{1}{2}gt^2\end{aligned}$$

33. Accelerated Motion of Bodies Having an Initial Velocity.

In our discussion of accelerated motion we have thus far considered only the case of bodies having an accelerated motion starting from rest. If, for example, a body which is acted upon by the force of gravity fall from rest, its initial velocity is zero and its velocity at the end of any instant is $v = gt$. If, however, a body be thrown downward with an initial velocity v' , it is evident that we shall have to add to the velocity gt the initial

velocity v' ; that is, at the end of any given interval the velocity will be represented by the equation

$$v = v' + gt$$

The space passed over during any interval of time will then be

$$s = v't + \frac{1}{2}gt^2$$

In general then we may write

$$\begin{aligned} v &= v' \pm gt \\ s &= v't \pm \frac{1}{2}gt^2 \end{aligned}$$

where the $+$ sign is used when the acceleration is positive and the $-$ sign when the acceleration is negative.

Examples. 1. A body thrown downward from a very high building has imparted to it an initial velocity of 20 ft. per sec. Find (a) its velocity, and (b) the space passed over in 4 seconds, assuming the acceleration to be 32 ft. per sec. per sec. *Solution:* (a) *Since the acceleration is positive, we may write* $v = 20 + (32 \times 4) = 148$ ft. per sec. (b) $s = (20 \times 4) + (\frac{1}{2} \times 32 \times 16) = 336$ ft.

2. A body is projected vertically upward with an initial velocity of 250 ft. per sec. Find (a) its velocity at the end of the 4th second; (b) the space passed over. *Solution:* (a) *In this case the acceleration is negative, that is, there is a loss of velocity amounting to 32 ft. per sec. It follows then that* $v = 250 - (32 \times 4) = 122$ ft. per sec. (b) $s = (250 \times 4) - (\frac{1}{2} \times 32 \times 16) = 744$ ft.

EXERCISES. 16. A body starting from rest falls 10 seconds. Find its velocity at the end of this time in (a) feet per second; (b) centimeters per second.

17. How far will the body fall during the 10 seconds in (a) feet? (b) centimeters?

34. Newton's Laws of Motion. The relation between force and motion is expressed by three important laws known as Newton's laws of motion. These laws were formulated by

Sir Isaac Newton (1642-1727), a famous English mathematician and physicist, and upon them are based some of the most important principles of modern mechanics. The three laws of motion are as follows:



Sir Isaac Newton

I. *Every body tends to preserve its state of rest or of uniform motion in a straight line unless compelled by some external force to change that state.*

II. *Change of motion is proportional to the impressed force, and takes place in the direction in which the force acts.*

III. *To every action there is equal and opposite reaction.*

35. Inertia. Balance a stiff card in a horizontal position upon the extended thumb and two fingers of the left hand. Place a coin in the center of the card. Now with the finger of the right hand snap the card sharply. If the experiment is skillfully performed the card will fly out, leaving the coin in place upon the fingers. The coin retains its position because of its inertia. A still more striking experiment illustrating inertia may be performed by balancing a marble upon the center of the card and snapping the card out by means of a spring, as shown in Fig. 23.



FIG. 23.—Illustrating inertia

Inertia is that property of matter by virtue of which a body at rest tends to remain at rest, and when in motion tends to continue in motion in a straight line. Inertia is the inability of a body of itself to change its state of rest or motion. A book lying on a table will, by virtue of its inertia, lie there forever unless acted upon by some external force; likewise a stone thrown upward will, by virtue of its inertia, move out into space in a straight line

if not acted upon by some external force, as for example, the force of gravity.

Illustrations of inertia are seen in the jerking of a sled from beneath a child sitting upon it; the hammering of water in water pipes when the faucet is suddenly closed; the stamping of snow from the feet; and in the forward motion of a person in a car when it suddenly comes to rest. In alighting from a moving car it is important to remember that inertia tends to carry the body forward in the direction of the motion of the car. For this reason we should always step off a car facing the direction of motion, and never facing to the rear, as is shown in Fig. 24.



FIG. 24. — In stepping off a moving car one should face in the direction of motion

An interesting illustration of inertia is that of the motion of the circus rider in jumping over a line. All the rider has to do in order to perform his act is to jump high enough to clear the line, the inertia of his body carrying him forward so that he lands again squarely upon the horse.

36. Hydraulic Ram. A practical illustration of the principle of inertia is that furnished by the operation of the hydraulic

ram. The hydraulic ram is an apparatus for elevating water to a height greater than its source. The condition necessary

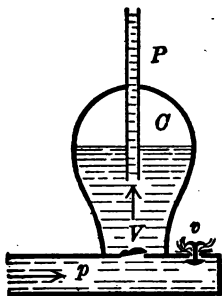


FIG. 25

Hydraulic ram, a practical application of the principle of inertia

for the operation of the ram is that there be a supply of running water. The water flows through a pipe *p* and out through a valve *v*, Fig. 25. As the speed of the steam through the pipe increases, valve *v* suddenly closes, thus causing the water, because of the inertia, to force its way for an instant through the valve *V* into chamber *C*. The water in the pipe *p* now rebounds, relieving the pressure on the valve *v*, which falls by its own weight, thus opening the orifice at the end of the pipe. The process is again repeated, and more water is forced into chamber *C*. The air cushion in *C* tends to produce a steady flow in the vertical pipe *P*.

37. Momentum. The second law of motion may be called the law of momentum. *Momentum* is the quantity of motion which a moving body possesses; that is,

$$\text{momentum} = \text{mass} \times \text{velocity} = mv$$

The unit of momentum is the momentum of unit mass having unit velocity. In the c. g. s. system the unit of momentum is the momentum of a mass of one gram moving with a velocity of one centimeter per second. There is no generally accepted name for this unit, although the name "bole" was proposed by the Committee of the British Association. In the f. p. s. system the unit of momentum is the momentum of a mass of one pound having a velocity of one foot per second.

The momentum of a mass of 10 pounds moving with a velocity of 10 feet per second is $10 \times 10 = 100$. Also, the momentum of a mass of 10 tons moving with a velocity of 10 yards per second, reduced to the same unit, is $2000 \times 10 \times 3 \times 10 = 600,000$.

The momentum of a body may be changed by changing its mass or its velocity, or both.

38. Further Illustration of the Second Law of Motion. An interesting illustration of the second law of motion is that seen in the effect of gravity on a projectile, as shown in Fig. 26.

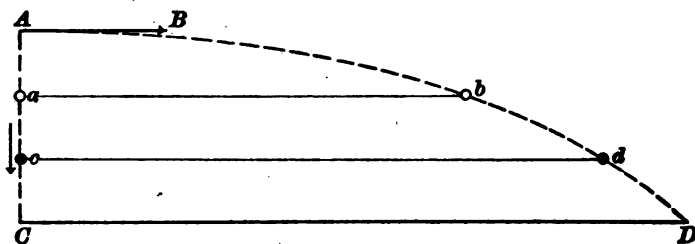


FIG. 26. — Both balls reach the ground at the same time

Suppose that a ball is fired horizontally from a cannon in the direction AB and at the same instant a similar ball is dropped vertically downward, in the direction AC . Since a force has the same effect in producing motion whether the body upon which it acts is at rest or in motion, or whether the body is acted upon by that force alone or by other forces at the same time, it follows that both balls will reach the ground simultaneously. When one ball is at a , the other will be at b ; and when the ball falling vertically has reached the position c , the second will be at d , and so on.

39. Action and Reaction. The third law of motion states that to every action there is an equal and opposite reaction; that is, every force is two-sided in its nature. If we push on a wall with a given force, the wall reacts (pushes back) with an equal force. In rowing a boat we act on the water, and the water in turn reacts on the boat, causing it to move. The bird in flying acts on the air with its wings; the air reacts on the bird, giving it motion.

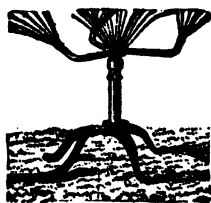


FIG. 27.—Action and reaction

An excellent illustration of action and reaction is that seen in the case of the rotating lawn sprinkler. The water in flowing from the sprinkler, Fig. 27, reacts upon the curved arms causing them to rotate. The action of the sprinkler is exactly similar to that which occurs when a person attempts to jump from a light boat to the shore. As the person jumps forward (action), he kicks the boat backward (reaction).

EXERCISE 18. Would a rotating lawn sprinkler work in a vacuum?

40. Relation of Action and Reaction to Momentum. The terms action and reaction may be interpreted to mean force. When the powder in a gun explodes it acts upon both the bullet and the gun with an equal force. Now force is proportional to change of momentum, and since the forces of action and reaction are equal it follows that the momentum of the gun is equal to the momentum of the bullet. This relation of action to reaction may be expressed by an equation as follows:

$$mv = m'v'$$

in which m and v represent the mass and velocity of the gun, and m' and v' the mass and velocity of the bullet. The velocity of the bullet will be as many times greater than the velocity of the gun as the mass of the gun is greater than the mass of the bullet. The lighter the gun, therefore, the greater its "kick"

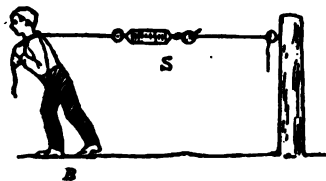


FIG. 28

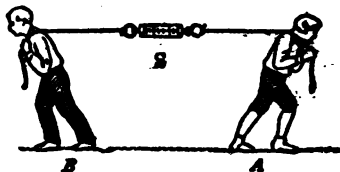


FIG. 29

or recoil. If bullet and gun were of equal masses they would fly apart when the powder explodes with equal velocities.

EXERCISES. 19. Suppose that a ball of mass 1 lb. is fired from a cannon of mass 1 ton, with a velocity of 1000 ft. per second. What will be the velocity of the gun's recoil?

20. When an apple falls to the earth its momentum toward the earth according to the third law of motion, is equal to the momentum of the earth toward the apple. How does the velocity of the earth compare with that of the apple?

21. A boy pulls on a rope, as shown in Fig. 28, with a force of 50 lb., as registered by the spring balance *S*. (a) What force is exerted on the rope? (b) What force is exerted on the post?

22. If a second boy take the place of the post, Fig. 29, and each pulls with a force of 50 lbs., what will be the reading of the spring balance?

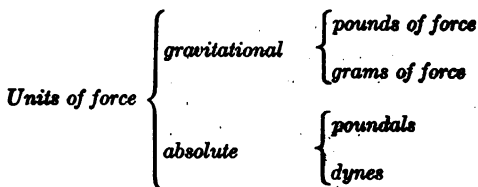
41. Measurement of Force. The magnitude of a force may be measured in two ways (a) by the push or pull exerted, and (b) by the product of the mass moved and the acceleration imparted to it.

One of the most usual methods of measuring the pull resulting from the application of a force is by means of the spring balance, or dynamometer, as it is sometimes called. Attach to the hook of a spring balance a given mass and lift the mass against gravity. The pointer of the instrument moves to a certain position on the scale. This indicates, in pounds or grams as the case may be, the force with which the earth attracts the body. Now, attach the hook of the balance to some object, say a nail or a hook in the wall, and pull upon it. The reading of the instrument again indicates the magnitude of the force exerted.

The force exerted upon a given mass may also be measured by the acceleration which is imparted to it. This is the method usually employed in scientific determinations of the magnitude of a force. To thus determine the magnitude of a force acting upon a body it is necessary to know the mass of the body and its acceleration. The product of these two factors is a measure of the force; that is, $F = ma$.

The units of force employed in this country are of two kinds: (a) the gravitational units and (b) the absolute units, each

being measured in terms of both the English and the metric systems. The gravitational units are used in nearly all ordinary practical measurements; the absolute, in accurate scientific measurements. The following outline may be of service in making clear the relation of the two sets of units.



42. Gravitational Units of Force. The gravitational units of force are those which compare the push or pull exerted by a force with the attraction due to gravity for a given mass. The English gravitational unit is the force of a pound (also called the weight of a pound). The *force of a pound* is a force equivalent to the attraction of the earth for a pound mass. The *force of a gram* (weight of a gram) is a force equivalent to the attraction of the earth for a gram mass. Since the attraction of the earth for a given mass varies slightly for different places, the gravitational units of force likewise vary. The variation for ordinary practical measurements, however, is so small as to be negligible.

43. Absolute Units of Force. The absolute units of force, the poundal and the dyne, are derived from the product of unit mass of a body and the acceleration imparted to it. The *poundal* is that force which will give to a pound mass an acceleration of one foot per second per second. The *dyne* is that force which will give to a gram mass an acceleration of one centimeter per second per second. Since the absolute units are used primarily in making accurate scientific measurements, it is not highly important, in an elementary work on physics, that this subject receive special attention. Two things with respect to the absolute units, however, are impor-

tant for the student to keep in mind, namely, (a) that in accurate scientific measurements the absolute units *are* used, and (b) that from the absolute units there are derived some of our most common practical units, such as the watt, and the kilowatt.

44. The Relation of Absolute to Gravitational Units. The relation of absolute to gravitational units may be expressed, approximately as follows:

$$1 \text{ pound of force} = 32 \text{ poundals}$$

$$1 \text{ gram of force} = 980 \text{ dynes}$$

The above values are arrived at thus. In gravitational units the force of a pound, for example, is the force with which the earth attracts a pound mass. Absolute units, on the other hand, are measured in terms of unit mass and unit acceleration; that is, $F=ma$. Now if a pound mass were allowed to fall freely in a vacuum, its acceleration at sea level would be about 32 feet per second per second (more accurately 32.16), and in a like manner, a mass of one gram would have an acceleration of about 980 centimeters per second per second. We say then that the force of a pound measured in gravitational units is equivalent to about 32 absolute units (poundals), and that a force of one gram in gravitational units is equivalent to about 980 absolute units (dynes).

EXERCISES. 23. A mass of 10 grams held in the hand exerts upon the hand, due to the attraction of the earth, a force of 10 grams. What is the force in dynes?

24. A mass of 1 kilogram rests upon the table. What force does it exert upon the table in (a) grams of force? (b) dynes?

25. A magnet exerts a force of 6860 dynes on a piece of iron. Find the force in grams.

COMPOSITION AND RESOLUTION OF FORCES

45. Graphic Representation of Forces. A force is fully described when we know three things about it; namely, (a) its point of application, (b) its magnitude, and (c) its direc-

tion and sense. Thus, when we say, "A force of 10 pounds acts vertically downward on a body at the point A" we fully describe the force, because we designate its point of application, its magnitude (10 lb.) and its direction and sense (vertically downward).

Forces, velocities, and accelerations may be represented graphically by means of lines. Thus the line, AB , Fig. 30,



FIG. 30

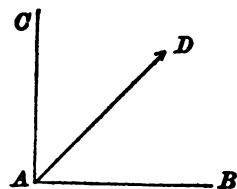


FIG. 31

represents a force acting from A to B . If we let a length of one inch represent a force of 10 pounds, then a line 6 inches in length will represent a force of 60 pounds. Likewise, a velocity of 20 miles per hour in a northeasterly direction may be represented in magnitude direction and sense by a line 20 centimeters in length drawn from A to D , as shown in Fig. 31. When drawing upon

the blackboard, the inch may conveniently be used as the scale unit; when drawing upon paper, the centimeter, or in some cases the millimeter, is the unit employed.

46. Composition of Forces. If two or more forces act upon a body at the same time the resultant force may be determined graphically. The various forces acting upon a body are called *components*; a single force which acting alone will produce the same results as the components, is called the *resultant*. The process of finding the resultant of a number of forces is called the composition of forces. We may in a like manner speak of the composition of velocities and accelerations. In the composition of forces, velocities, and accelerations there are a number of important cases which are considered in an elementary manner in the following topics.

47. Parallel Forces in the Same Straight Line. The resultant of two or more forces acting in the same straight line is equal to the algebraic sum of the forces. Components

acting to the right or upward from a given point are said to have the plus sign; those acting downward or to the left, the minus sign.

EXERCISES. 26. If a man on top of a freight car, which moves with a velocity of 30 ft. per second, run in the direction in which the car is moving with a velocity of 10 ft. per second, what is the resultant (actual) velocity?

27. Suppose that the man run in the opposite direction with a velocity of 10 ft. per second. What will be the resultant velocity?

28. Three forces, one due to the tide, one due to the wind, and the third the force exerted by the engine, act in the same straight line upon a boat. The tide acts to the westward with a force of 4 units; the wind acts in the same direction with a force of 12 units; the engine drives the boat to the eastward with a force of 50 units. Find the magnitude and direction of the resultant.

48. Parallel Forces Not in the Same Straight Line. The resultant of two forces acting in the same direction but not in the same straight line is equal to the sum of the forces, and the point of application of the resultant divides the distance between the forces into lengths inversely proportional to the forces. This may be illustrated by means of two spring balances and a weight, Fig. 32. Let a given weight W (12 lb., for example) be suspended at such a point B that the force on the spring balance S is 8 pounds and the force on S' 4 pounds. The resultant W equals $4+8=12$. The relation of the two arms AB and BC may be expressed thus,

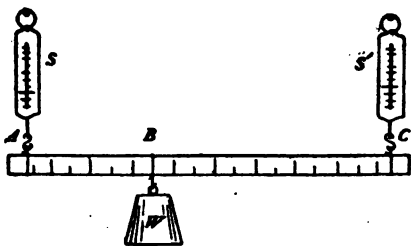


FIG. 32. — Parallel forces

$$AB : BC = 4 : 8$$

It is important to note that the greater force (8) is on the side of the short arm, and the lesser force (4) is on the side of the long arm.

EXERCISES. 29. If W , Fig. 32, exert a force of 20 lb., what will be the force on S and S' if W be placed (a) midway between A and C ? (b) $\frac{1}{4}$ of the distance from A to C ? (c) $\frac{1}{5}$ of the distance from C to A ?

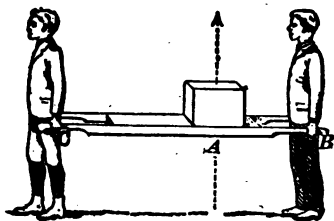


FIG. 32

30. If AC , Fig. 32, be 100 cm in length, where must a weight of 300 grams be placed so that the force exerted on S shall be 75 grams and on S' 225 grams. Note.—Let x equal the long arm AB and $(100-x)$ the short arm.

31. Two boys, Fig. 33, carry between them a block of ice weighing 90 lb. The distance AB is 2 ft. and the distance AC is 3 ft. Find what part of the load each boy carries.

49. Forces Making an Angle with Each Other. The resultant of two forces making an angle with each other is equal to the diagonal of the parallelogram formed by the lines representing the forces as sides.

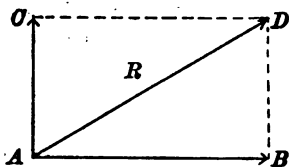


FIG. 34

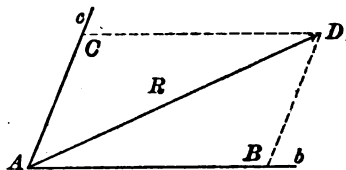


FIG. 35

Two cases are to be considered. First, when the angle formed by the components is a right angle, Fig. 34; and second, when the angle formed by the components is not a right angle, Fig. 35. In the first case the resultant R is the hypotenuse of a right angled triangle, and we may write

$$R = \sqrt{AB^2 + AC^2}$$

In the second case two elementary methods of finding the resultant are possible: (a) by experiment with spring balance; (b) by the graphic method.

50. Experimental Determination of the Resultant. Suspend two spring balances S and S' from hooks in the frame of the blackboard, and attach to them a weight W , or a third spring balance S'' , Fig. 36. Lay off a line on OA equal in inches to the numerical reading of the balance S . Lay off another line on OB numerically equal in inches to the reading of the balance S' . Now complete the parallelogram, and the diagonal OD will represent in direction and magnitude the resultant. The value of this resultant in inches should be numerically equal to the weight W , or the reading at S'' .

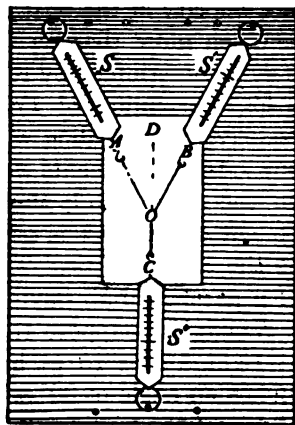


FIG. 36

51. Graphic Method of Finding the Resultant. To find the resultant of two components which act upon a body at a given angle. Suppose that A , Fig. 37, represents a boat on the surface of a lake, and that it is acted upon by two forces, the wind and the tide. The wind tends to give it a velocity in the direction AB of 20 feet per minute; the tide, acting at an angle of 60° to the direction of the wind, tends to give it a velocity of 15 feet per minute. We wish to find the direction and magnitude of the resultant velocity. In other words, we wish to find the actual direction and velocity of the boat. Lay off on paper a line AB 20 centimeters in length to represent a velocity of 20 feet. From the point A , Fig. 37, lay off AC 15 centimeters in length, making with AB an angle of 60° . Now complete the parallelogram. The

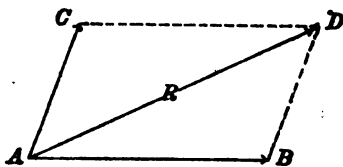


FIG. 37

line AD represents the magnitude and direction of the resultant, its length in centimeters being numerically equal to the velocity of the boat in feet per minute.

When more than two components are given, the resultant may be determined by repetition of the parallelogram of forces.

52. Resolution of Forces. In the cases just considered, namely, those dealing with the composition of forces or velocities, the components were given to find the resultant. When, on the other hand, the resultant is given to find the component, the process is called the *resolution of forces or velocities*, as the case may be. This problem requires the construction of a parallelogram having the given resultant as its diagonal.

Example. Suppose that the resultant of two forces acting at right angles to each other is 100 dynes. The resultant makes an angle of 30° with one of the forces. Find the magnitude of the forces. *Solution:* Draw two lines AX and AY at right angles to each other, Fig. 38. From the point A draw

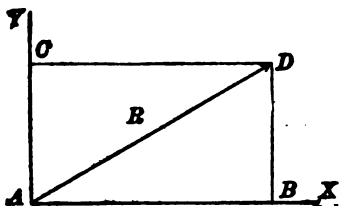


FIG. 38

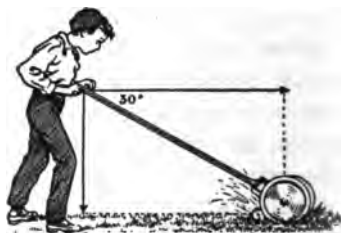


FIG. 39

the line AD , making an angle of 30° with AX and having a length of 10 centimeters, say, each centimeter representing 10 dynes. The line AD represents the resultant (100 dynes) in magnitude and direction. Now from the point D draw a line DB parallel to AY ; also draw from D the line DC parallel to AX . The lines AB and AC represent the magnitude and direction of the components sought.

EXERCISE. 32. A boy pushes a lawn mower with a force of 50 lb., the force acting in the direction of the handle, which makes an angle of 30° with the horizontal, Fig. 39. Find, by drawing, what part of the force acts, (a) horizontally, and (b) vertically.

CIRCULAR MOTION

53. Centrifugal Force. We shall now devote our attention to curvilinear motion, and some of its practical applications. When a body moves in a circle, it tends at every instant to fly off in a straight line, in obedience to the first law of motion. This tendency of the rotating body to move in a straight line causes it to exert a force which is directed outward from the center of rotation. This outwardly directed force is centrifugal force. The presence of such a force in the case of a rotating body may be demonstrated by attaching a metal ball, or other small mass, to a string and whirling the ball around in a vertical plane. A distinct pull on the string will be felt, becoming greater as the velocity of rotation increases. The outward force exerted by the rotating ball is called *centrifugal force*; the reaction exerted upon the ball by the string toward the center of rotation is called *centripetal force*.

Centrifugal force is exerted *by* the rotating body and is directed from the center toward the circumference; centripetal force is exerted *on* the body and is directed from the circumference toward the center. These forces are equivalent to action and reaction; they are equal to each other in magnitude, and are oppositely directed.

One of the most familiar practical applications of centrifugal force is that of the "governor" of the steam engine, a demonstration section of which is shown in Fig. 40. The pipe *D* admits steam from the boiler to the engine. If there were no regulating valve in *D* the engine would run with variable speed; that is, when the pressure in the boiler is high, the speed is great, and when the pressure is low the speed is small. The function of the governor is to so regulate the amount

of steam admitted to the engine as to give uniform motion to the fly wheel. The flow of steam is controlled by the turning

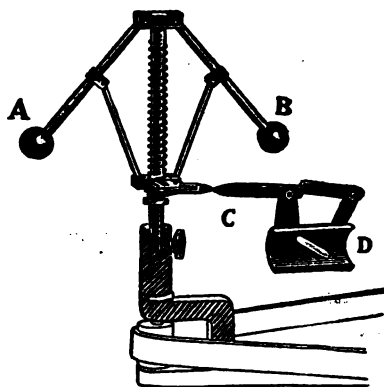


FIG. 40. — Governor of a steam engine

of the valve *D*. The balls *A* and *B* are caused to rotate about a vertical axis by means of a drive belt from the engine. When the steam pressure is high the engine speeds up. As the rotation of the governor balls *A* and *B* increases they tend to fly outward from the central axis, due to the increase in centrifugal force. Now as the balls move outward the lever arm *C* is pulled up-

ward, which motion tends to close the valve in the steam pipe *D*. When the steam pressure is low the speed of the engine diminishes, and as a consequence the governor balls fall. The depression of *A* and *B* opens the valve in *D*, thus admitting more steam to the engine. It thus appears that the amount of steam admitted to the engine, and therefore the speed of the engine, is kept constant by the operation of the governor balls.

There are many other applications of centrifugal force, some of which will be studied in later paragraphs. Before proceeding with a further study of applications of the principle, however, we shall consider the laws which govern centrifugal and centripetal forces.

54. Laws of Centrifugal Force. The laws of centrifugal (and also centripetal) force are as follows:

I. *Centrifugal force is proportional to the mass of the rotating body.* That is, the greater the mass the greater the force. For example, if a mass of 1 pound be whirled around with

a given speed, a given centrifugal force (pull on the string) will be exerted; if, now, a mass of 10 pounds be rotated with the same speed, the centrifugal force will be 10 times as great as in the first case.

II. *Centrifugal force is directly proportional to the square of the speed.* If the speed of the rotating body be increased from 1 foot per second to 10 feet per second, the centrifugal force will be increased from 1 to 10^2 , that is, from 1 to 100.

III. *Centrifugal force is inversely proportional to the radius of rotation.*

The three laws may be expressed by means of an equation,

$$F = \frac{mv^2}{r}$$

in which F is the force, m the mass of the rotating body, v its speed, and r the radius of rotation. This equation expresses the force in absolute units.

Example. A mass of 6 pounds is whirled around at the end of a string 2 feet in length with a speed of 4 feet per second. Find the pull on the string due to rotation in (a) poundals; (b) pounds. *Solution:* $F = (mv^2)/r = (6 \times 16)/2 = 48$ poundals = 1.5 pounds of force.

EXERCISE. 33. A mass of 98 grams attached to the end of a string 10 cm in length is whirled around with a speed of 10 cm per second. Find the centrifugal force exerted by the rotating body in (a) dynes; (b) grams of force.

55. Illustrations of Centrifugal Force. Experiments with whirling table. (a) If some mercury and water be placed in a receptacle and rotated rapidly, the mercury will take a position in the equatorial region of the globe, with a zone of water on either side, Fig. 41. The mercury, having a greater mass per unit of volume than that of the water, exerts a greater centrifugal force, and hence gets farthest from the axis of rotation. This experiment illustrates the principle

of the modern cream separator, by means of which the cream is separated from the milk.

(b) If a circular band of metal be whirled about a central axis, Fig. 42, it will flatten at the poles, due to the fact that

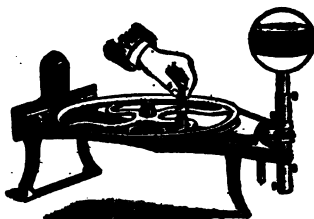


FIG. 41

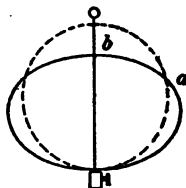


FIG. 42

the particles in the region *a* have a greater speed, and hence exert a greater centrifugal force than do the particles in the region of the poles *b*.

Further illustrations of the action of centrifugal force may be seen in the ordinary affairs of everyday life. For example, the mud and water on the carriage or automobile wheel are thrown off due to the centrifugal force exerted by the rotating bodies. Water in a pail or bucket may be whirled around in a vertical plane. In this case the water is kept in the pail by the centrifugal force tending to throw it away from the center. Also, a bicycle rider in going around a corner instinctively leans inward to overcome the centrifugal force, which tends to overturn him. For the same reason the circus rider leans in toward the center of the ring. Likewise, on railway curves the outer rail is laid higher than the inner rail to overcome the centrifugal force exerted by the train. Centrifugal machines for the drying of salt, sugar, and clothes by rapid motion are now in common use.

56. The Cream Separator. Two of the most important practical applications of the principle of centrifugal force are those which have to do with the modern cream separator, and the Babcock milk tester.

Fresh milk consists of fats (cream) and skim milk (water, casein, and sugar) intimately mixed. The cream occurs in the milk in finely divided particles. If fresh milk is allowed to stand for several hours in shallow pans the cream particles, being slightly lighter than the milk particles, slowly rise to the surface where the cream may be skimmed off. The gravity, or shallow pan method, which was in common use up to the time of the invention of the centrifugal separator, was a very slow and relatively inefficient process. In gravity separation and skimming, as usually practiced, 5 per cent or more of the cream remained in the milk; with a good centrifugal separator 98 to 99 per cent of the butter fat is obtained. This latter process also has an advantage in that it is possible to separate the cream quickly and as soon as the milk is taken



FIG. 43

Cream separator

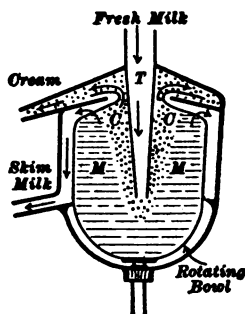


FIG. 44

from the cows. One type of the cream separator is shown in Fig. 43.

The essential parts of a cream separator are a bowl, which is capable of rotating at high speed, surrounded by a stationary jacket, and a gearing device for rotating the shaft

connected to the bowl. The modern separator contains a set of discs within the bowl. When in operation the discs and bowl make from 6000 to 8000 revolutions per minute. In Fig. 44 there is shown a section of the separating chamber, the discs being omitted in order that the essential principle may be made clear. The bowl is rapidly rotated by means of a "worm" gear which is not shown. Fresh milk enters through the tube *T*, and soon acquires the rotary motion of the bowl. Both the cream and the milk are thrown outward from the central axis of rotation by centrifugal force. But the milk particles *M* being heavier than the cream particles of the same size experience the greater force and soon occupy the outer section of the bowl, the cream particles, *CC*, being nearer the center. The skim milk escapes from the bowl through holes at the top near the circumference, while the lighter cream escapes through holes nearer the axis of rotation.

56a. The Babcock Milk Tester. This mechanical device is nothing more than a simple form of the cream separator in

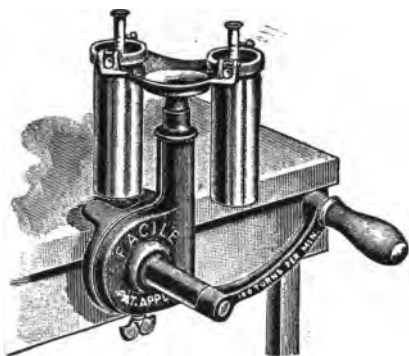


FIG. 45. — A two-bottle type of the Babcock milk tester

which the milk is placed in a series of two or more specially prepared and graduated test tubes, Fig. 45. The milk to be tested is placed in the tubes, which are then whirled rapidly about a central axis. The tube supports are pivoted so as to allow the tubes to swing outward on rotation. When the axis is rotated, the

tubes assume a horizontal position, the skim milk appearing in the outer part (bottom of the tube), and the cream at the top. By means of the scale which is etched upon each

tube, it is possible at once to determine the amount of butter fat (cream) present in the milk.

This testing device was invented by Professor S. M. Babcock and was offered by him without royalty charges to the dairy farmers of the country. By means of the Babcock test it is possible for any dairyman easily and accurately to determine the butter fat producing qualities of each member of his herd.

GRAVITATION, GRAVITY, WEIGHT

57. Gravitation and Gravity. *Gravitation* is the force with which every particle of matter in the universe attracts every other particle. The law of universal gravitation was first announced by Newton as follows: *Every body attracts every other body with a force proportional to the product of their masses and inversely proportional to the square of the distance between their centers.* This law may be written

$$F = k \frac{m \times m'}{d^2}$$

in which F is the force of gravitation, measured usually in pounds or dynes; m and m' are the masses of the bodies; d is the distance between their centers; and k is a constant depending on the kind of unit employed.

By assuming the truth of the general law of gravitation, astronomers have been enabled to describe accurately the motion of the heavenly bodies, as, for example, to predict eclipses, the return of comets, and to discover new planets.

Gravity is the force of attraction which exists between the earth and other bodies. Gravitation is a general term, referring to the universal attraction which exists between all bodies; gravity is a specific term, referring to the attraction of the earth for bodies, usually considered at or near its surface.

58. Weight. The *weight* of a body is the force by which it is attracted to the earth; weight therefore may be defined as a measure of gravity.

Different uses of the term. In the study of mechanics the term weight occurs many times, and is sometimes employed in three different senses, as follows: (a) The term weight may be used when referring to an object, as, for example, we may say, "Put the weight on the scale pan," referring thereby to a definite piece of metal; (b) in the second place it is employed to designate a force equivalent to the attraction of gravity, as defined in the preceding topic; (c) and, finally, the word weight is sometimes used as synonymous with mass. This last use of the term is confusing and misleading.

Distinction between mass and weight. It is manifestly very important that a careful distinction be made between the mass of a body and its weight. Mass refers to the quantity of matter in the body; weight, to the force with which the earth attracts the body. If an object be moved from one place to another, its mass is not affected thereby; its weight, on the other hand, may be changed, since the weight of a body is determined by the force of gravity acting upon it, and the force of gravity for a given mass varies slightly for different points upon the earth's surface.

59. The Relation of the Weight of a Body to Its Position on the Earth. Since the weight of a body is the measure of the force of gravity acting upon it, and since the force of gravity for a given mass varies for different positions with respect to the earth's surface, it follows that the weight of a body may vary from place to place. The relation of weight with reference to the earth's surface may be stated briefly as follows:

Weight at the surface. The nearer a body is to the center of the earth, so long as it remains upon the surface, the greater is its weight. Thus a given mass will weigh more at the base of a mountain than at the top; also, since the polar radius of the earth is about 13 miles less than the equatorial radius, and therefore a body at the poles is nearer the center of the earth than it is at the equator, it follows that a given mass

at or near the poles will weigh more than at or near the equator.

Weight above or below the surface. The weight of a body above or below the surface is less than at the surface. A mass weighing 100 pounds, for example, at the surface of the earth will weigh less than 100 pounds if taken up in a balloon or down into a mine.

60. Centrifugal Force and Weight. There are two reasons why a given body weighs less at the equator than at the poles. The first is because the force of gravity, as has already been explained, is less at the equator than at the poles; and the second is, that the centrifugal force at the equator is greater than at or near the poles. Bodies at the equator have a velocity, due to the rotation of the earth, of more than 1000 miles per hour. The resulting centrifugal force is about $1/289$ of the force of gravity. Now, since centrifugal force is proportional to the square of the speed, and the square of 17 is 289, it follows that if the earth should rotate 17 times as fast as it now does, bodies at the equator would weigh nothing; and should the rate of rotation increase beyond this value, they would fly off into space.

THE PENDULUM

61. Introductory. The most common use of the pendulum is exemplified by the pendulum clock, Fig. 46, in the measurement of time. Galileo was one of the first to investigate and establish the laws of the pendulum. It is related that he discovered the fact that the vibrations of a pendulum are performed in equal intervals of time, that is to say, that the vibrations are isochronous, by observing the vibrations of a swinging chandelier in a cathedral. Timing the swings of the chandelier by means of his pulse he found that the interval required to complete a swing was the same whether the arc was relatively great or small.

A *pendulum* is a body suspended so as to vibrate freely. A *complete vibration* is a swing from one side to the other and back again; that is, from *A* to *B* to *C* and back to *A* again, Fig. 47. A *simple vibration* is a swing from one side of the arc to the other; that is, from *A* to *C*.

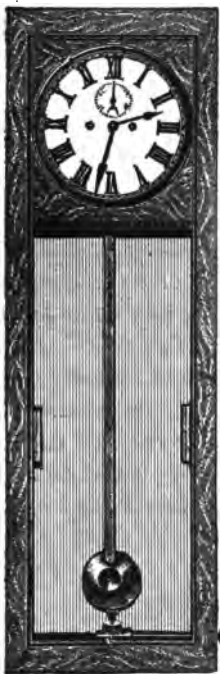


FIG. 46
Laboratory clock

The *amplitude* is one half the arc described in a single swing.

The *period*, or time of vibration, is the time required to make one complete vibration. It is important to note that the term period refers to the time required to make one vibration and has no reference to the time required for the pendulum to come to rest.

The *frequency*, or number of vibrations per second, is designated by the letter *n*.

A pendulum may be simple or compound. A *simple pendulum* (sometimes called a mathematical pendulum) is considered to be a material particle suspended by a weightless thread. Of course no such pendulum actually exists, since any thread, however small, must have some weight. A small lead bullet, however, suspended by a fine thread may be considered as an illustration of a simple pendulum. A *compound pendulum* is any body suspended so as to vibrate freely. A meter stick vibrating about one end is a compound pendulum. In fact all pendulums in actual use are compound pendulums, differing only in their approximation to the ideal simple type. The pendulum of a clock, for instance, is a compound pendulum in which most of the mass is in the bob.

62. The Relation of the Period to the Frequency. If a pendulum makes 20 vibrations in 10 seconds, the number of vibrations per second will be $n=20/10=2$. Also its period will be $T=10/20=\frac{1}{2}$ second. Hence it appears that the period of a pendulum is equal to the reciprocal of the number of vibrations per second; that is,
 $T=1/n$.

63. Motion of the Pendulum
Explained. Consider the pendulum, Fig. 48, to be drawn aside to the point A. It is acted upon by the force of gravity, repre-

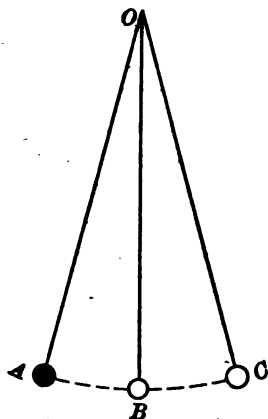


FIG. 47

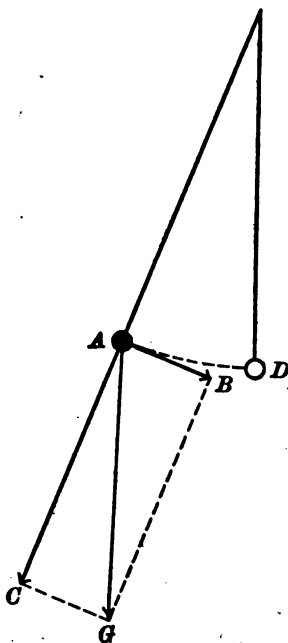


FIG. 48

sented by the line AG. This force may be resolved into two components; one, AC, producing a tension in the string, and the other, AB, tending to produce motion toward the position of rest at D. The pendulum, then, tends to move from A to D due to a component of the force of gravity. It continues to swing beyond D due to its inertia. If there were no friction to interfere, the pendulum would rise as high on one

side of the arc as on the other; that is to say, it would never come to rest.

64. Laws of the Pendulum. It may be shown experimentally, as well as mathematically, that the following laws apply to the simple pendulum.

I. *The period of vibration of a pendulum is directly proportional to the square root of its length.* This means that if the period of a simple pendulum 1 meter in length is 1 second, then the period of a similar pendulum 4 meters long will be 2 seconds; that is,

$$T : T' = \sqrt{l} : \sqrt{l'}$$

II. *The period of vibration is inversely proportional to the square root of g .* Since the value of g varies from place to place (see Table X, page 27), it follows that the period of a given pendulum may be different at different places.

III. *The period of vibration is independent of the amplitude.* This law holds strictly if the amplitude is not greater than 5 or 6 degrees. The law may be verified by counting the number of vibrations per minute of a pendulum when vibrating through a relatively large arc, and again for a small arc. The period will be the same in both cases.

IV. *The period of vibration is independent of the mass of the bob.* Given two pendulums of equal length, the bob of one being an iron ball, the bob of the other a wooden ball. It will be found that both pendulums make the same number of vibrations per second; that is, the period of each is the same.

These laws of the pendulum may be combined into a single equation,

$$T = 2\pi\sqrt{\frac{l}{g}}$$

in which T is the period, in seconds; l is the length of the equivalent simple pendulum in feet or centimeters; g is the acceleration of gravity in feet (32), or in centimeters (980),

per second per second. The constant π (3.1416) occurs here, as in a great many mathematical equations, because the equation involves the ratio of the circumference of a circle to its radius.

EXERCISE. 34. Find the period of a pendulum 108.9 cm in length at Washington, D. C., g being 980.1 cm per sec. per sec.

65. Center of Oscillation. Having given the length of a compound pendulum, it is important to know how to find the length of an equivalent simple pendulum, since l in the equation of Art. 64 is the length of a simple pendulum. To find what fraction of the length of a meter stick, suspended at one end, is equal to the length of an equivalent simple pendulum, we may proceed as follows: Suspend side by side a meter stick and a pendulum consisting of a lead bullet attached to a fine thread, Fig. 49. Set the two pendulums vibrating and then shorten the simple pendulum until the two vibrate in the same time. The meter stick represents a compound pendulum; the bullet and thread, a simple pendulum. That length of the meter stick, which is equivalent in length to a simple pendulum, is the distance from the point of suspension S to the point C , which corresponds to the position of the bob of the simple pendulum. The point C is called the *center of oscillation* of the compound pendulum. When we speak of the length l of a compound pendulum we mean a length that is equivalent to a simple pendulum having the same period. If the compound pendulum be a thin uniform rod, as in the case of the meter stick, and if suspended from the end, l is $\frac{2}{3}$ of the entire length of the meter stick. If the pendulum is not uniform, however, as in the case of a ball bat, the length l has to be determined by experiment.

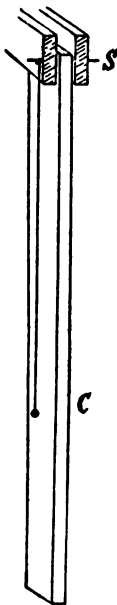


FIG. 49
Center of
oscillation

EXERCISE. 35. What is the period of vibration of a thin uniform rod 12 ft. in length, the value of g being 32 ft. per second per second?

66. Center of Percussion. Grasp a stick (such as a meter stick) firmly at the end. Now with the extreme end of the stick strike sharply upon the edge of some projecting object, such as the edge of the laboratory table. A distinct downward jerk will be felt on the fingers of the closed hand. Again, strike the stick, this time quite close to the hand. A blow is felt, this time in the palm of the hand. Finally strike the stick at a point about two-thirds of the distance from the hand to the end. No jar is felt by the hand, and the experimenter experiences a feeling of having struck an effective blow. This point is called the center of percussion. The *center of percussion* is a point where a blow, given or received, is most effective and produces the least strain on the support or axis of motion. The baseball player soon learns at what point on the bat he can deal the most effective blow and at the same time produce the least tingle in his hand.



FIG. 50
Clock
pendulum

In a compound pendulum the center of percussion is a point coincident with the center of oscillation. In the case of the experiment with the stick, we must consider the arm together with the stick as constituting the pendulum.

67. Mechanics of the Clock Pendulum. Since vibrations of a pendulum are performed in equal intervals of time, that is, they are isochronous, all that is needed in order to use the pendulum as a recorder of time, is some mechanical device to keep the pendulum vibrating and to enable it to regulate the motion of the hands. The motive power of the clock is sup-

plied by weights or springs; the motion of the hands is regulated by means of an escapement C , Fig. 50. As the pendulum swings to and fro the projections of the escapement catch alternately in the teeth of the escapement wheel, D , thus allowing only one tooth to escape for each double swing. If the escapement wheel, therefore, has 30 teeth, it will rotate once while the pendulum makes 30 complete vibrations.

In order that the periods shall be equal, the length of the pendulum must always be the same. In summer the pendulum, however, lengthens, and hence the clock tends to lose time. In winter the pendulum shortens and the clock gains time. Corrections must therefore be made for changes in length due to changes in temperature. This may be done by moving the bob up or down by means of a nut or thumb screw. Changes in the length of a pendulum due to changes in temperature may also be automatically corrected by means of compensating devices. A compensation pendulum is one that is made of two or more metals so regulated, as to expand in opposite directions (Art. 196), and thereby keep the length of the pendulum constant.

68. Use of the Pendulum in Determining g . If the period of a pendulum of given length be determined by experiment, the value of the acceleration g due to gravity at any place may be determined by means of the equation

$$T = 2\pi\sqrt{\frac{l}{g}}$$

EXERCISE. 36. The period of a simple pendulum 1 m in length on Pike's Peak, Colorado, is 1.004 seconds. Find the value of g at that place.

REVIEW EXERCISES

1. Define: motion, velocity, acceleration. Give illustration of positive acceleration; negative acceleration.
2. Explain and illustrate the distinction between speed and velocity.
3. Explain the use of the following equations, and explain the meaning of each term: $v = at$; $s = \frac{1}{2}at^2$; $s = \frac{1}{2}gt^2$.

4. A body acted upon by a constant force starts from rest and at the end of the 1st second has a velocity of 5 ft. per second; at the end of the 2d second, 10 ft. per second, and so on. What is its velocity (a) at the end of 5 seconds? (b) 5 minutes?

5. (a) Over what space does the body (problem 4) pass in 10 seconds? (b) in 1 minute?

6. How far does it go during the 10th second?

7. The force applied by the engine to the driving shaft of an automobile causes it to change its velocity from 0 to 20 ft. per second during the 1st five seconds. How far will the car move under the action of this force if steadily applied for 20 seconds?

8. A body falls from rest for 10 seconds. Over what space, in feet, does it pass (a) during the first 5 seconds of its fall? (b) during the last 5 seconds?

9. Solve problem 8 in metric units, using $g = 980$ cm per second per second.

10. A body is thrown upward with a velocity of 320 ft. per second. (a) For how many seconds will it rise? (b) How high will it rise?

11. Define: force, pound of force, gram of force, poundal, dyne.

12. Explain and illustrate the difference between the mass of a gram and the force of a gram.

13. (a) A force of 10 lb. is equivalent to how many poundals? (b) A force of 640 poundals is equivalent to how many pounds of force?

14. A mass of 245 grams is acted upon by a force which imparts to it an acceleration of 8 cm per second per second. Find the force in (a) dynes; (b) grams of force.

15. Distinguish between the weight of a gram and the force of a gram.

16. State and give an illustration of the application of (a) Newton's first law of motion; (b) second law; (c) third law.

17. Define and illustrate: inertia, momentum.

18. Explain each term of the equation $mv = m'v'$ and explain, also, to what law of motion it applies.

19. Compare the momentum of a body having a mass of 2 ounces and a velocity of 40 ft. per second with that of a body having a mass of 2 lb. and a velocity of 2 ft. per second.

20. A shot is fired from a cannon having a mass of 1 ton. The velocity of the shot is 1000 ft. per second, that of the cannon 2 ft. per second. Find the mass of the shot.

21. Explain the terms (a) composition of forces; (b) resolution of forces. To what other physical quantities may the principles of composition and resolution be applied?

22. A 12 ft. plank spans a stream. A man weighing 200 lb. crosses on the plank. Call one end of the plank *A* and the other *B*, and assume that the man walks from *A* toward *B*. What part of his weight rests upon each support when he is (a) 4 ft. from *A*? (b) 6 ft. from *A*? (c) 8 ft. from *A*?

23. A boy draws a sled by means of a rope which makes an angle of 40° with the horizontal. He exerts on the rope a force of 30 lb. What is the horizontal component of this force acting upon the sled? The vertical component? Make a drawing to illustrate the solution of this problem.

24. A stream which is a mile wide, flows with a velocity of one mile per hour. A man at *A* on one side desires to cross to *B*, which lies exactly opposite *A*. The man steers his boat directly across stream and rows at the rate of one mile per hour. (a) Where, with reference to *B*, will he land? (b) If he directs his boat up stream to a point one mile above *B* and rows until he reaches the opposite shore, where will he land? (c) If he heads his boat directly up stream and rows for an hour, where will he be at the end of that time?

25. Define: centrifugal force; centripetal force.

26. Explain the use of the following equation and state the meaning of each term contained therein: $F = mv^2/r$. Does this equation give results in absolute or gravitational units?

27. A mass of 2 lb. is attached to a string 2 ft. in length and is rotated with a speed of 5 ft. per second. Find the centrifugal force which it exerts in pounds.

28. Explain by means of a sketch how the governor of a steam engine regulates the supply of steam from the boiler to the engine so as to give uniform motion to the fly wheel.

29. Explain briefly the operation of the cream separator.

30. When a bicycle rider goes around a curve how does he lean, and why?

31. Define: gravitation; gravity; weight.

32. Explain the difference between mass and weight.

33. Explain why a body weighs less at the equator than at the poles.

34. Define: pendulum, simple pendulum, amplitude of vibration, period.

35. What is the relation of the period of vibration T , to the frequency n ?

36. State the laws of the pendulum.

37. Explain the use of the following equation and the meaning of each term: $T = 2\pi\sqrt{l/g}$.

38. How is the period of the pendulum affected (a) when its length is increased? (b) when the force acting upon it is increased?

39. Consider a pendulum consisting of a spherical metal bob attached to a string. What is the relation of its period to (a) its amplitude? (b) the mass of the bob?

40. A given pendulum makes 240 vibrations in 2 minutes. What is its frequency (number of vibrations per second)? (b) what is its period?

41. Find the period of a simple pendulum (a) 4 meters in length; (b) 4 ft. in length.

42. Explain how to find by experiment the center of oscillation of a compound pendulum; the center of percussion.

43. It is related that at one time Thomas Jefferson proposed that the United States Government adopt as the legal standard of length a metal rod of uniform thickness and density which would "beat" seconds (period of half complete vibration = 1 second) when suspended from one end. What would be the length of such a rod if the determinations were made at Washington, D. C.?

44. Explain how it is possible to determine the acceleration of gravity g for any given place by means of a pendulum of known period.

CHAPTER III

MECHANICS OF SOLIDS (Continued)

WORK AND POWER

69. Work. *Work* is the overcoming of resistance through space. As used in physics, the term work involves two ideas, *force* and *space*. If a man were to hold up a heavy weight without giving it motion, he would not be doing work in the physical sense. The moment he moves the body, that is, applies force through space, he does work.

$$\begin{aligned} \text{Work} &= \text{force} \times \text{space} \\ w &= Fs \end{aligned}$$

In the equation $w = Fs$, the space s is measured in the direction of the application of the force. For example, if a bucket of mortar having a weight (force) of 75 pounds be lifted vertically by means of a rope from A to B , Fig. 51, a distance of 12 feet, the work performed would be $75 \times 12 = 900$ foot pounds. Suppose now that the load (75 pounds) be carried up the ladder a distance of 13.5 feet. While the space traversed by the workman in going up the ladder is 13.5 feet, yet the space s through which he actually exerts the force of 75 pounds against gravity is, as before, 12 feet, and the work done is again 900 foot pounds.



FIG. 51
 $Work = Fs = F \times 12$

Work does not involve the factor of time. If a weight be lifted from the floor to the table in 10 seconds, a given amount of work is done. Again, if

the same weight be lifted through the same space in 10 minutes, or in 10 hours, the same amount of work is done as in the first case. A train of cars hauled from one station to another requires a given amount of work, no matter what the time involved. Likewise, the work done by a carpenter in sawing a board is measured only by the resistance overcome and the space through which the saw cuts.

70. Units of Work. Since work is force times space, the units in which work is measured depend upon the units chosen for force and space. There are, therefore, for work, as in the case of force, two sets of units, the gravitational and absolute.

$$\text{Units of work} \left\{ \begin{array}{l} \text{gravitational} \left\{ \begin{array}{l} \text{foot pound} \\ \text{gram centimeter} \end{array} \right. \\ \text{absolute} \left\{ \begin{array}{l} \text{foot poundal} \\ \text{erg} \end{array} \right. \end{array} \right.$$

The *foot pound* is the work done by a force of one pound acting through a space of one foot. The *gram centimeter* is the work done by a force of one gram acting through a space of one centimeter. The kilogram meter is sometimes used instead of the smaller unit, the gram centimeter. A *kilogram meter* is the work done by a force of one kilogram acting through a space of one meter.

The *foot poundal* is the work done by a force of one poundal acting through a space of one foot. The *erg* is the work done by a force of one dyne acting through a space of one centimeter.

The two units of work ordinarily employed are the foot pound and the erg. Since the erg is a very small quantity, a larger unit called the joule is sometimes used. A *joule* is ten million (10,000,000) ergs. The relation of gravitational to absolute units of work is expressed as follows:

$$\begin{aligned} 1 \text{ foot pound} &= 32 \text{ foot poundals} \\ 1 \text{ gram centimeter} &= 980 \text{ ergs} \end{aligned}$$

EXERCISES. 1. A weight of 10 pounds is lifted vertically to a height of 10 feet. Find the work done in (a) gravitational units; (b) absolute units.

2. A force of 10 grams acts through a space of 10 cm. Find the work done in (a) gravitational units; (b) absolute units.

3. A horse pulling a load of 1 ton along a smooth road exerts a force of 500 pounds. How much work in foot pounds is done by the horse if the load be hauled a distance of 1 mile?

71. Power. *Power* is the time rate of doing work. It is work divided by time; that is,

$$power = \frac{work}{time} = \frac{w}{t}$$

Units of power. The absolute metric unit of power is the watt, named in honor of James Watt, the inventor of the steam engine. A *watt* is the expenditure of energy at the rate of ten million (10,000,000 or 10^7) ergs per second. A *kilowatt* (kw) is 1000 watts.

The English unit of power is the horsepower (hp). When the horsepower was first proposed as the unit of power it was thought that a strong horse was capable of doing about 33,000 foot pounds per minute, or 550 foot pounds per second, and this value was originally accepted as the unit of power. The modern legal definition of the horsepower in the United States, as defined by the Bureau of Standards, is as follows: One *horsepower* is equivalent to 746 watts. Unless very accurate determinations are desired, however, the older definition is still largely used, in which case we may write

$$horsepower = \frac{foot\ pounds}{550 \times seconds} = \frac{watts}{746}$$

In the case of metric units,

$$watts = \frac{ergs}{10^7 \times seconds}$$

The power of an ordinary horse is about $\frac{3}{4}$ horsepower; that of the average man is about $\frac{1}{7}$ horsepower. The power

of the railroad locomotive varies from 500 to 5000 horsepower; that of the engines of our large ocean liners from 10,000 to 40,000 horsepower. In Fig. 52 there is shown a giant electric passenger locomotive, manufactured recently by the Westinghouse Electric Company, which weighs 275 tons and which has a power capacity, based on a one hour rating,



FIG. 52.—Giant electric locomotive and the persons who built it. This locomotive has a power capacity of 42,000 horsepower

of 42,000 horsepower. A locomotive of this type is capable of hauling a heavy train on a level grade at a speed of from 60 to 70 miles per hour.

It is important to note that while the power of an average man is, for continuous work, far below that of a horse, yet for a short time the man may work at a greater rate than that of a horsepower. A person in running upstairs, for instance, works at a rate considerably above a horsepower.

EXERCISES. 4. During the construction of a building 4950 lb. of brick were elevated to a height of 20 ft. in 10 minutes. At what rate, in hp., was the work done?

5. A 500 kilogram weight was lifted to a vertical height of 10 meters in 10 seconds. At what rate was the work done in (a) gram centimeters per second? (b) ergs per second? (c) watts?

6. How many gallons of water can an 8-horsepower engine throw to a height of 30 ft. in a quarter of an hour, assuming that a gallon of water weighs 8 lb.?

7. An engine lifts 198 tons of ore per hour from a mine 1000 ft. deep. Find the power of the engine in (a) horsepower; (b) kilowatts.

72. Energy. *Energy* is the capacity that a body has for doing work. The steam in an engine possesses energy because in expanding it is capable of doing work. The water in a mill dam, the coiled spring of a watch, the muscles of the body, all possess energy because they have the capacity for doing work.

The units in which energy is measured are the same as the units of work; namely, the foot pound, foot poundal, gram centimeter, and the erg.

Energy is of two kinds, potential and kinetic.

73. Potential Energy. *Potential energy* is the energy which a body possesses by virtue of its position, or by virtue of its tendency to change chemically. A body lifted from the floor to the table possesses energy by virtue of its position, because if it were allowed to fall from the table to the floor it would do work. A lump of coal possesses potential energy because of its affinity for oxygen, that is, its tendency to burn. Gunpowder, likewise, possesses potential energy because of its tendency to explode.

The potential energy of a body due to its position may be measured by the work required to put it in place. For example, a body lies upon the table. Its potential energy with respect to the floor is equal to the work required to lift it from the floor to the table.

$$\text{Potential energy} = \text{work} = \text{force} \times \text{space}$$

$$P. E. = w = Fs$$

EXERCISES. 8. A piece of metal weighing 10 lb. is lifted from the floor to the table, a distance of 3 ft. Find its potential energy in foot pounds.

9. A mass of 20 grams rests on a shelf 3 meters above the floor. What is its potential energy with respect to the floor in (a) gram centimeters? (b) ergs?

10. A mass of 1 kilogram is lifted to a height of 2 meters. Find its potential energy in (a) kilogram meters; (b) gram centimeters; (c) ergs.

74. Kinetic Energy. *Kinetic energy* is the energy which a body possesses by virtue of its motion. We instinctively avoid bodies that are in rapid motion. Experience has taught us that such bodies possess energy—the greater the motion the greater the energy. Let us consider the case of the bullet and the gun. We have learned from the third law of motion that the momenta of the two are equal. This does not imply, however, that their energies are equal. The energy of the bullet is enormously greater than that of the gun because of its greater velocity. The kinetic energy of a body varies directly as its mass and the square of its velocity. If the velocity of a body be doubled its energy is increased fourfold; if the velocity be trebled its energy is increased ninefold, and so on.

If a bullet be dropped from a height of 2 feet into a pail of soft clay it will penetrate to a certain depth, depending on the softness of the clay. If now the bullet be dropped from a height of 8 feet, such that its velocity on striking the clay is twice as great as in the first instance, it will penetrate to nearly 4 times the depth that it did in the former case. It can be shown that the following equation for kinetic energy holds:

$$K.E. = \frac{1}{2}mv^2$$

in which m is the mass of the body and v its velocity. This equation expresses the kinetic energy in absolute units (foot pounds or ergs).

Example. A body having a mass of 16 pounds moves with a velocity of 20 feet per second. Find its K.E. *Solution:* $K.E. = \frac{1}{2}mv^2 = \frac{1}{2} \times 16 \times 400 = 3200$ foot pounds = 100 foot pounds.

EXERCISES. 11. A mass of 64 lb. is moving with a velocity of 10 ft. per second. Find its K.E. in (a) absolute units (foot poundals); (b) gravitational units (foot pounds).

12. A mass of 196 g, moving with a velocity of 10 cm per second, has what K.E. in (a) ergs? (b) gram centimeters?

75. Transformation of Energy. Potential energy and kinetic energy are so related that when one disappears the other appears. If a stone be thrown upward it has its maximum kinetic energy at the instant it leaves the hand, because its velocity at that instant is greatest. As it rises its kinetic energy decreases and its potential energy increases. When it reaches its highest point its potential energy is a maximum; its kinetic energy, zero. Thus, in ascending there is a transformation from kinetic to potential energy; in descending a reverse transformation occurs; that is, the potential energy again becomes kinetic energy, reaching a maximum when the velocity is the greatest.

76. The Conservation of Energy. The law of the conservation of energy states that the energy in the universe is constant in quantity; it cannot be created or destroyed. When work is done, one body loses energy and another gains it. The doing of work, therefore, involves a transference, and often a transformation as well, of energy. The potential energy possessed by a lump of coal is transformed into heat energy in the furnace, then to the steam in the engine, thence to the motion of the wheels, and so on. No energy is destroyed; it is only transformed from one form to another.

EQUILIBRIUM, CENTER OF GRAVITY, STABILITY

77. Introductory. In its general dimensions as well as in the enormous size and weight of the structural members composing it, the Quebec bridge, now in an advanced stage of construction, surpasses any other structure of the kind ever erected. The one bridge structure in the world that approaches it in magnitude is the famous Firth of Forth

bridge in Scotland, the main-channel-span of which is nearly 100 feet shorter than that of the Quebec bridge. Both bridges are of the cantilever type. The channel-span of the Quebec bridge, measured between centers of towers, is 1800 feet. The design and fabrication of the steel for this structure therefore presented engineering problems for which no precedents existed, and the first attempt to build the bridge resulted in 1907 in a collapse of the structure in which many lives were



FIG. 53.—One of the supporting piers of the great Quebec bridge, the steel base upon which the truss beams rest weighing 400 tons

lost. The present bridge is on the same site as the original structure. The two main piers which support the bridge contain approximately 60,000 cubic yards of masonry and steel. One of these piers, the supporting section of which is shown in Fig. 53, goes to a depth of 60 feet below the bed of the river, and the other to a depth of 80 feet.

One of the shore spans of the Quebec bridge is shown in Fig. 54. A glance at the great steel arm projecting out over

the river will at once incite in the mind of the observer the question as to how it is possible to build such a steel structure without support of some kind. The way it is done is to start at the pier as a center and to build the span out equally in opposite directions, that is, toward the shore on one side and toward the center of the river on the other. In other words, the project presents a problem of *equilibrium*. In constructing cantilever bridges of this sort, arms are built out from each shore until they meet, or until they are close enough to receive the central span.

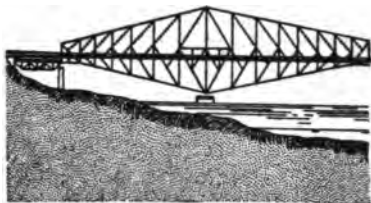


FIG. 54.—One of the shore spans of the Quebec bridge

The problem of equilibrium, as illustrated in the construction of bridges of this type, is one which constantly confronts the structural engineer.

78. Equilibrium. Moment of a force. Suppose that a force F , Fig. 55, acts on a lever arm of length d , thus tending to produce rotation about the axis O . The product of the force F times the lever arm d is called the moment of the force F . Such a turning moment is also sometimes called a *torque*.

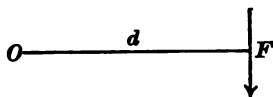


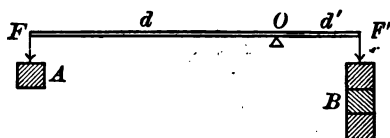
FIG. 55.—Moment of a force, Fd

$$\text{Moment of a force} = \text{force} \times \text{lever arm} = Fd.$$

In engineering practice a knowledge of torques produced by forces is of the utmost importance.

Equilibrium. A condition of equilibrium is essentially a condition of balance. For example, suppose that two masses, A and B , are attached to the ends of a light rigid rod, as shown in Fig. 56. Suppose further that the weight of B is three times as great as A . Now the system will manifestly

be in equilibrium about the support or axis O when the moment Fd is equal and opposite to the moment $F'd'$. Since



F' is three times as great as F , it follows that O must be in such a position that d is three times as great as d' ; that is,

FIG. 56
Condition of equilibrium

$$Fd = F'd'$$

$$1 \times 3 = 3 \times 1$$

In the above examples we have assumed that the weight of the rod is negligible as compared with F and F' .

79. The Problem of Moments Continued. In the preceding article we considered the law of moments as applied to the simple lever.

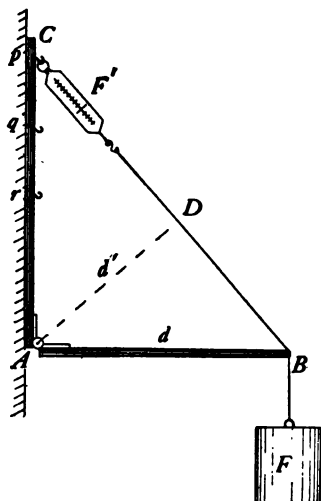


FIG. 57
Moment $Fd = \text{Moment } F'd'$

The mathematical expression of this law may be very much more complex than that illustrated by a simple rigid bar. A case in point is that illustrated by Fig. 57. Here we have a bar AB pivoted at A and supported at right angles to the wall AC by means of a cord CB . A force F acts downward on AB tending to produce rotation about the point A . The moment of this force is Fd . An opposing force F' acts on AB along the line BC . The lever arm for this force (F') is d' , a line drawn from A and at right angles to CB . The moment in this case is $F'd'$.

Now since the system is in equilibrium, that is, the bar AB is at rest, the two moments are equal to each

other in magnitude and oppositely directed, and we may therefore write,

$$Fd = F'd'$$

In the case of a moment of a force, the lever arm (d or d') is always a straight line measured from the axis of rotation (A in Fig. 57) to the line of direction of the force considered, and at right angles to it. Thus d is the lever arm for the force F which acts downward, and d' is the lever arm for the force F' which acts in the direction BC .

80. Center of Gravity. The *center of gravity* of a body is the point of application of the resultant of all the forces of gravity acting upon it. It is the point about which the body may be balanced. If a meter stick, for example, be balanced upon the finger, the center of gravity of the stick lies in the body directly above the point of support.

The center of gravity of a regular homogeneous body is at its geometrical center. The center of gravity of a cube lies at the point of intersection of its diagonals; the center of gravity of a circular disc is at its center of figure.

The center of gravity of an irregular body, as, for example, a chair, may be determined by suspending it successively from two different points and noting the intersection of the direction of the plumb line. If a piece of metal such as iron or lead, be suspended by means of a string, the device is known as a plumb line, that is, a line determining a vertical direction; the piece of metal is called the "bob." Suspend from two points E and C an irregular shaped piece of board, Fig. 58, and note the point of intersection of the lines E and C . The center of gravity of the board

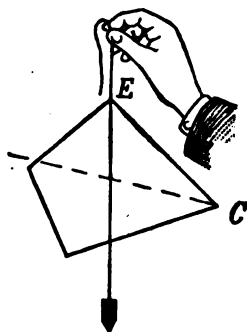


FIG. 58
Center of gravity

lies on a line passing through the intersection of lines E and C , midway between the faces. In a similar manner it may be shown that the center of gravity C of a plane trian-

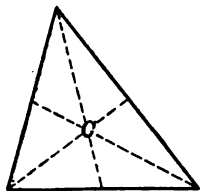


FIG. 59
Center of gravity
at intersection of
median lines

gular figure of uniform density lies at the intersection of its median lines, Fig. 59. The center of gravity of a body may lie entirely outside the material of the body, as in the case of a ring or of a lamp chimney. Center of gravity is sometimes called center of mass.

81. Line of Direction. The *line of direction* is a straight line passing through the center of gravity of a body and the center of the earth. Whether a body stands or falls depends upon the position of its line of direction with respect to its base. If this line falls within the base, I , Fig. 60, the body will stand; if it falls without the base, II , the body

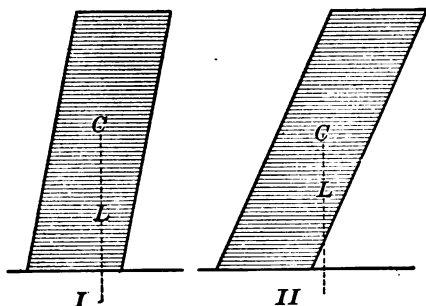


FIG. 60.—Stability determined by line of direction L

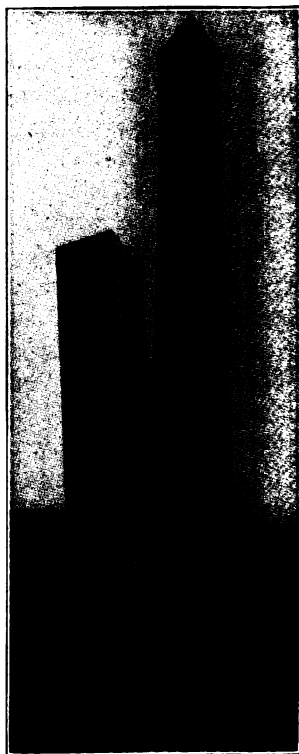


FIG. 61—Leaning towers of Bologna

will fall. There are in Europe a number of "leaning towers" which illustrate in a very striking manner the relation of the stability of a body to the position of its line of direction. Among the most noteworthy structures of this type are the leaning towers of Bologna, Italy, Fig. 61. The taller of these two towers is 320 feet in height and leans out of plumb by 4 feet; that is, the top of the tower leans 4 feet from a plumb line dropped through the middle of the base. The shorter tower is 163 feet in height and is out of plumb by 10 feet. One of the most famous leaning towers is that of the bell tower of the Cathedral of Pisa, Italy. This tower is 179 feet in height and its top leans from the vertical, as computed in 1910, a distance of 16.5 feet.

82. Three States of Equilibrium. The three states of equilibrium which a body may possess are stable, unstable, and neutral, illustrated by a cone as shown in Fig. 62. A body is said to be in *stable equilibrium* if a turning motion about any point in its base, such as would occur in tipping it over, tends to raise its center of gravity. A book lying on the table is in stable equilibrium because its center of gravity rises if it be turned upon its edge. A cone resting upon its base, *A*, Fig. 62, is a good illustration of stable equilibrium.

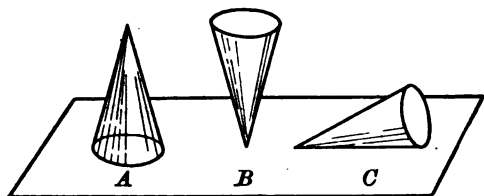


FIG. 62.—Three states of equilibrium

A body is in *unstable equilibrium* if a turning motion tends to lower its center of gravity, *B*, Fig. 62.

A body is in *neutral equilibrium* if a turning motion neither raises nor lowers its center of gravity, as in the case of the cone lying on its side. A spherical ball is also an excellent illustration of neutral equilibrium.

Stability of a body. The stability of a body is determined by the amount of work required to overturn it; that is, the amount of work necessary to lift the center of gravity of the body through a vertical distance, ab , Fig. 63. There are

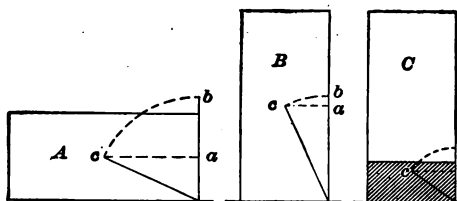


FIG. 63.—Condition of stability

two ways by which the stability of a body may be increased; namely, (a) by broadening the base, (b) by lowering the center of gravity. In A, B, and C of Fig. 63 we have three

bodies of the same shape and size. In C the center of gravity is lower than in A and B, due to the loading of one end of the vessel with some heavy material.



FIG. 64

EXERCISES. 13. Explain (a) why A, Fig. 63, is more stable than B; (b) why C is more stable than B.

14. Which is the more stable, a load of hay or a load of coal, each weighing the same? Why?

15. A person standing with his heels and back against a wall cannot pick up anything from the floor in front of him without falling. Why?

16. Why does a person carrying a heavy bucket of water throw out the free arm, as shown in Fig. 64?

MACHINES

83. Introductory. The present is preeminently an age of machinery. A thousand kinds of work that was formerly performed by hand is now turned out in great quantities by machines. For example, formerly a tailor cut out a single piece of cloth with handshears; now a machine operator cuts at a single stroke fifty pieces. In the old days a shoemaker could turn out a single pair of shoes in a day; now wonderfully complex machines turn out several hundred times as much

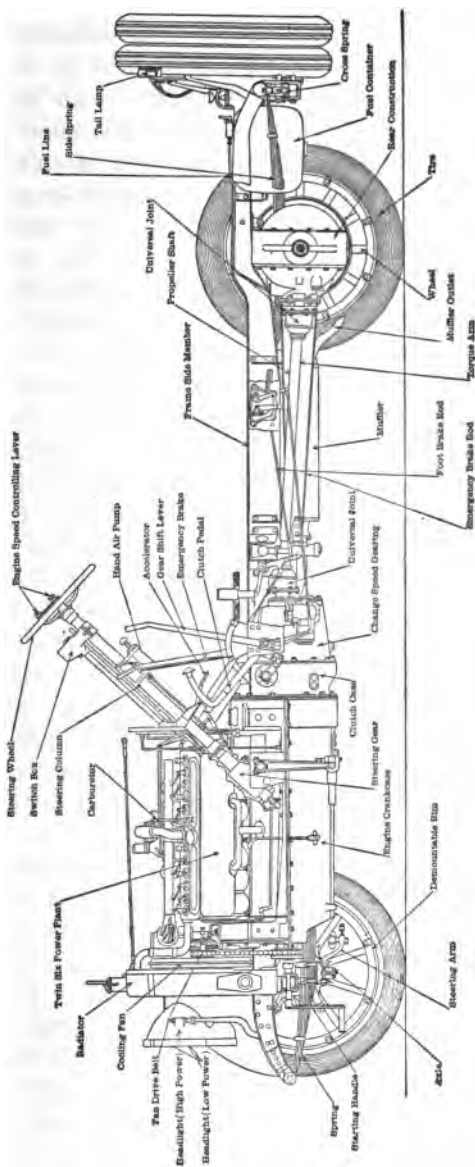


FIG. 65.—Chassis outline of a high power automobile. In a machine of this sort we have practically every form and class of the lever, the wheel and axle, the screw, the inclined plane, as well as the gas engine with its various accessories, and the electric motor

work in a day as was done by the old-fashioned shoemaker. Machines have been designed and are now in use which are capable of soling 600 pairs of shoes in a single day.

One of the most complicated and at the same time one of the most effective and commonly used machines today is the automobile, the chassis outline of which is shown in Fig. 65. In this machine we have practically every form and class of lever, the wheel and axle, the screw, the inclined plane (exemplified in the blades of the fan), as well as the gas engine with its various accessories, and the electric motor. To understand the working of the automobile even in an elementary sense one must not only know something of the principles of mechanics and thermo-dynamics, but one must possess a fair knowledge of electricity as well. From an educational viewpoint the most significant thing about the automobile is not its wonderful development in recent years, the great perfection of its parts, or its amazing distribution and use; the significant thing is that the introduction of this popular means of locomotion has demonstrated the fact that thousands of people, men and women, and children too, for that matter, possessed a mechanical skill and understanding which hitherto had been entirely unsuspected. Many a boy who in school has struggled with indifferent success over the simplest problems of mechanics has later on surprised his teachers, and himself, by his ability to master the complicated mechanism of a newly acquired automobile.

84. Kinds of Machines. It must not be understood, however, that the term "machine" has reference only to such complicated pieces of apparatus as mentioned in the preceding paragraphs. A jackknife is a machine, as is also a lead pencil and a sewing needle. In a scientific sense a *machine* is a device for transferring or transforming energy. A steam engine together with the boiler, is a machine for transforming the potential energy of coal into the kinetic energy of mechanical motion. A dynamo is a machine which may be used for

transforming the energy of mechanical motion into the energy of an electric current. A hammer, a pair of scissors, or a hand spike are all types of machines for transferring energy from one point to another.

All machines, however complicated, are made up of one or more of the mechanical powers, or simple machines. The simple machines are as follows: The lever, wheel and axle, inclined plane, pulley, wedge, and screw.

In elementary physics it is customary, in solving problems relating to simple machines, to consider the friction factor as negligible and to assume, usually, that the parts of a machine are rigid and without weight. When these factors (friction and weight of the moving parts) are taken into account, problems relating to machines are sometimes very complicated and require for solution the principles of advanced mechanics.

85. Law of Machines. In accordance with the law of the conservation of energy, the work done by a force acting on a machine must equal the work done by the machine. This principle as applied in mechanics is expressed by the general law of machines: *The force, multiplied by the distance through which it acts, is equal to the resistance overcome, multiplied by the distance through which it acts.* This statement of the law, of course, takes no account of friction.

The general law of machines may be demonstrated as follows: Weight the end of a rod so that it will balance about some point, for example, one-third of the distance from one end, Fig. 66. This constitutes a simple machine. To one end of the lever thus formed suspend a mass of 1 unit of force, F , and to the other end 2 units of resistance R . The system is in equilibrium.

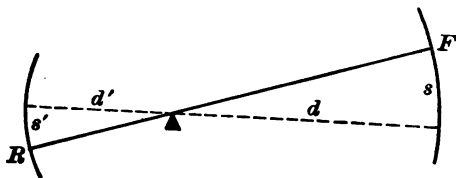


FIG. 66.—Illustrating the law of machines

If F be moved through a distance s , R will move through a distance s' . Now, from the law of machines, we may write

$$Fs = Rs'$$

and since $s : s' = d : d'$ we may write

$$Fd = Rd'$$

in which F is the force and d the force arm; R is the resistance overcome and d' the resistance arm.

86. Mechanical Advantage. Several advantages may be derived from the use of a machine. For example, first we may apply a force in the most advantageous direction, as in the lifting of a weight by passing a rope over a pulley. Second, we may gain in speed at the expense of force, as exemplified in the gearing of a bicycle. And third, we may use a small force to overcome a large resistance, as in the case of lifting a heavy weight by means of a lever. When we speak of the mechanical advantage of a machine we refer to the ratio of the resistance overcome to the force applied; that is,

$$\text{mechanical advantage} = \frac{R}{F} = R:F$$

87. Mechanical Efficiency. The *efficiency* of a machine is the ratio of the useful work gotten out of the machine to the total work put into it. In equational form

$$\text{efficiency} = \frac{\text{work out}}{\text{work in}}$$

If a machine delivers 60 foot pounds of useful work for every 100 foot pounds put into it, its efficiency is $60/100 = 60$ per cent. This means that 40 per cent of the energy is lost through friction or through other causes. A perfect machine, that is, one operating without friction, would have an efficiency of 100 per cent. Since it is impossible to make such a machine, the work done by a machine is always less than the work put into it.

88. The Lever. A *lever* is a rigid bar capable of moving about a fixed point, called a fulcrum. There are three classes of levers, as shown in Fig. 67, in which F is the force applied

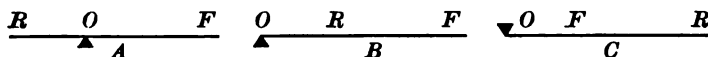


FIG. 67.—Three kinds of levers

to one end, R the resistance overcome, O the fulcrum, d the force arm, and d' the resistance arm.

The following points should be noted with respect to the lever: (a) The force arm d is measured from the point of application of the force F to the fulcrum O ; the resistance arm d' from the resistance R to the fulcrum. (b) In the case of a bent lever the arms d and d' are measured from the fulcrum

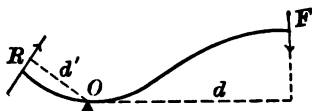


FIG. 68

to the lines of direction F and R , and at right angles to the same, Fig. 68. (c) Since for levers of the same length the force arm d is the greatest for the second class, it follows that for a given length, a lever of the second class offers the greatest mechanical advantage, as may be seen in Fig. 67. (d) A lever of the third class gives an advantage in speed at the expense of the force applied.

The law of the lever is that of the general law of machines, namely, $Fd = Rd'$.

EXERCISES. 17. Classify the levers of Figs. 69, 70, 71, 72, 73, 74 with respect to class.



FIG. 69

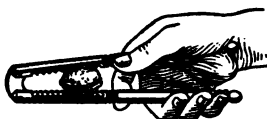


FIG. 70



FIG. 71



FIG. 72



FIG. 73

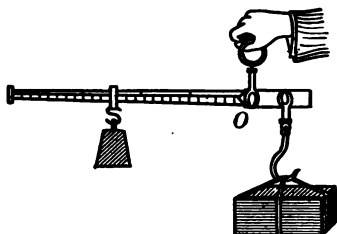


FIG. 74



FIG. 75

18. If a man exert a force of 100 lb. on a lever of the second class, at a point 5 ft. from the fulcrum F , what weight can be lifted, provided the resistance arm d' is 18 in. in length?

19. If a weight of 300 lb. act downward at M , the center of gravity of the wheelbarrow, Fig. 73, 1 ft. from the axis of the wheel (fulcrum), what upward force must the man exert, providing the distance from M to his hands is 3 ft.?

20. How many levers is the baggage-man shown in Fig. 75 using? To what class do these levers belong, assuming that the center of mass of the box is at its geometrical center?

89. The Wheel and Axle. The wheel and axle is an application of the principle of the lever. The large disc, Fig. 76, is the wheel; the small shaded disc is the axle. The force F

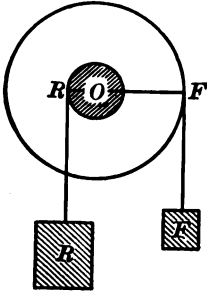


FIG. 76

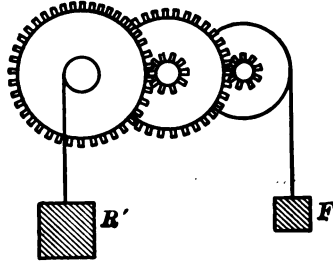


FIG. 77

Wheel and axle

is applied to a rope passing over the wheel; the resistance or weight R is lifted by means of a rope wound around the axle. The center of the system O is the fulcrum, $FO = d$ is the force arm, and $OR = d'$ is the resistance arm.



FIG. 78.—Automobile transmission gears

The law, as in the case of the lever, is $Fd = Rd'$. Since the radii of the two wheels are proportional to their diameters, and also to their circumferences, we may write $r : r' = d : d' =$

$c : c'$. These values, therefore, may be substituted for d and d' in the equation $Fd = Rd'$.

Other forms of the wheel and axle are seen in the train of cogwheels, Fig. 77, and in the "transmission" of an automobile, Fig. 78.

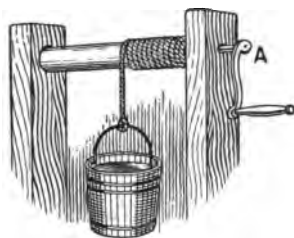


FIG. 79

23. If the length of the lever arm A of the windlass, Fig. 79, is 1.5 ft., and the circumference of the axle is 1.5 ft., what weight will be supported by a force of 10 lb.? When the handle makes one revolution, through what distance will the weight attached to the rope move?

90. The Pulley. A *pulley* is a wheel turning about an axis in a frame or block. A set of blocks containing one or more pulleys each, together with the attached rope, is called a block and tackle, Fig. 80. In Fig. 81 there is shown a lever and pulley system used in clearing land of stumps.

With respect to the point of support pulleys are of two kinds, fixed and movable. A *fixed pulley* is one that is fixed or fastened to a stationary support, as a beam or a wall, Fig. 82 A. A *movable pulley* is one that is attached to the weight or object to be moved. Fig. 82 B illustrates a system of one fixed and one movable pulley.

EXERCISES. 21. What force applied at F , Fig. 76, will support a weight of 100 lb., if the radius of the large wheel be 2 ft. and that of the small wheel (axle) 6 in.?

22. Suppose that for a given wheel and axle, similar to that of Fig. 76, the circumference of the wheel is 5 ft. Find the circumference of an axle such that a force of 20 lb. will support a weight of 100 lb.



FIG. 80
Block and
tackle

When F moves through a distance s , R moves through s' ; hence the law of the pulley is $Fs = Rs'$.

91. Mechanical Advantage of the Pulley. The law of machines, $Fs = Rs'$, may be experimentally verified for a number of typical cases by means of two or three pulleys and a spring balance, arranged as in the following figures:

(a) Fig. 82 A. In this case when F moves down one unit of distance, R moves up one unit, that is $s = s'$, and hence



FIG. 81.—Lever and pulley system used in clearing a field of stumps

$F = R$. A force of 10 pounds then at F will overcome a resistance at R of 10 pounds. The mechanical advantage in the case of the single fixed pulley is 1 : 1; that is, the only advantage gained is a change in the direction in which the force is applied.

(b) Fig. 82 B. Since we have here two ropes attached to the movable pulley in this case, F will move two units of space for R one unit; hence 1 unit of force at F will support

2 units of resistance at R . A force of 10 pounds at F will therefore exert a force of 20 pounds at R . The mechanical advantage in this case is 2 : 1.

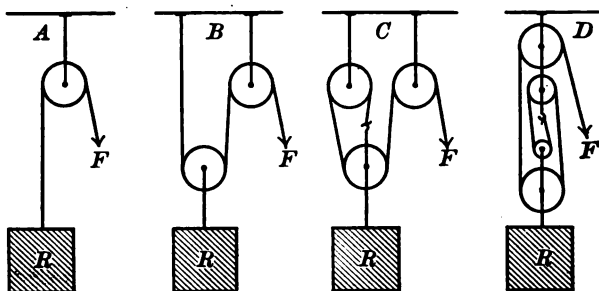


FIG. 82.—Mechanical advantage of the pulley

(c) Fig. 82 C. Here three ropes are attached to the movable pulley. When F moves 3 units of distance, R will move 1 unit; therefore 10 pounds of force at F will exert 30 pounds at R . The mechanical advantage here is 3 : 1.



FIG. 83.—Differential pulley

(d) Fig. 82 D. Four ropes are pulling (due to the force F) upon the movable pulley. When F moves through 4 units of space, R moves through 1 unit; a force of 10 pounds applied at F will therefore overcome a resistance R of 40 pounds. The mechanical advantage is 4 : 1.

(e) The *differential pulley*, Fig. 83, is a combination of the wheel and axle and the pulley.

The mechanical advantage of the differential pulley is relatively very great. In the case of the differential pulley shown in Fig. 83, the following equation applies:

$$Fr = \frac{1}{2}R(r-r')$$

in which F is the force applied and R is the resistance overcome, r and r' represent the radii of the pulleys of the fixed system.

EXERCISES. 24. A man weighing 160 pounds exerts the force of his entire weight downward at F , Fig. 82 C. Neglecting the friction of the rope and the pulleys, what weight (resistance R) can he lift?

25. The resistance R of Fig. 82 D is 2.5 tons. What force applied at F will be required to support R , friction being neglected?

26. A force of 100 pounds exerted vertically upward at F , Fig. 84, will support what weight at R , neglecting the weight of the pulleys and the friction factor?

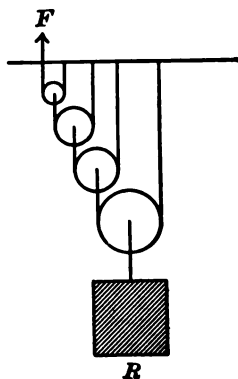


FIG. 84

92. The Inclined Plane. An *inclined plane* is a device for lifting heavy weights by sliding or rolling them up an incline, Fig. 85. In the case of the inclined plane the force F is most advantageously applied parallel to the incline, AC , Fig. 86. The distance through which the force acts is $s = AC$; the distance through which the resistance R is lifted vertically against gravity is $s' = BC$. The law of the inclined plane is therefore

$$Fs = Rs', \text{ that is}$$

$$F \times AC = R \times BC$$



FIG. 85.—Inclined plane

In Fig. 87 there is shown a device for loading logs upon a truck by means of skids (inclined plane), the engine of the truck furnishing the force F .

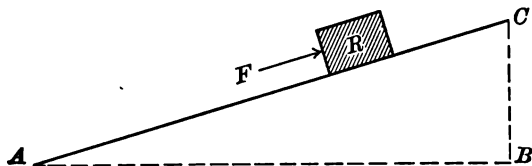


FIG. 86

EXERCISE. 27. What force applied parallel to the incline will be required to support a 200 lb. weight on a smooth plane, the incline of which is 16 ft., and the vertical height 4 ft.?



FIG. 87.—Inclined plane used in loading logs upon truck

93. The Wedge. A *wedge* is a modified form of an inclined plane. It may be considered as being made up of two planes placed base to base. The blade of a pocket knife, the end of a nail, the point of a needle are all wedge-shaped instruments. The wedge is usually used to overcome great resistance through small spaces, as in the splitting of logs, the lifting of heavy weights through very small distances, and so forth.

The force is usually applied to the wedge by means of a blow as from a hammer or sledge.

94. The Screw. A *screw* is a cylinder having a spiral groove cut around its circumference, Fig. 88. The spiral ridge is called the *thread* and the distance between two consecutive threads the *pitch*. The mechanical advantage of the screw is derived from a combination of the principles of the lever and the inclined plane.

Law of machines applied to the screw. When the screw is rotated once, it moves forward in the direction of its axis through a distance s' equal to the pitch. The screw usually is turned by means of a lever or wheel. The force is applied at the end of the lever, or at the circumference of the wheel. While the force moves once

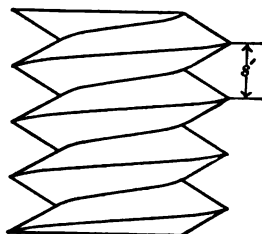


FIG. 88
Pitch of screw = s'

around the circumference of the wheel the resistance force R acts through a distance equal to the space s' between two consecutive threads (the pitch of the screw). The distance through which the force is exerted during one revolution is

$$s = 2\pi r$$

in which r is the radius of the wheel. The work done by the force therefore equals $F \times 2\pi r$, and the work done in overcoming the resistance is Rs' . We may therefore write

$$\begin{aligned} Fs &= Rs' \\ F \times 2\pi r &= Rs' \end{aligned}$$

Applications of the screw are manifold. For example, we have the common screw, and the bolt and nut, Fig. 89, the turnbuckle, Fig. 90, used to bring the ends of rods together, and the worm gear, Fig. 91, a type of which is frequently used in the driving gear of auto trucks. The speed counter, Fig. 92, shows how an endless screw (worm gear) meshing

into teeth on the circumference of a wheel can be used to determine the rotation of an axle. In using the speed counter



FIG. 89.—Bolt



FIG. 90.—Turnbuckle

the pointed end of the screw is thrust into the hole in the end of the axle and rotates with it.

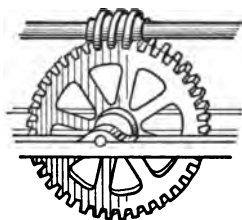


FIG. 91.—Worm gear



FIG. 92.—Speed counter

EXERCISES. 28. The distance from *A* to *B*, Fig. 93, is one inch. (a) How many threads to the inch on this screw? (b) What is the pitch *s'*? Express your answer in the fraction of an inch.

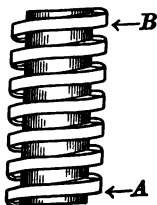


FIG. 93

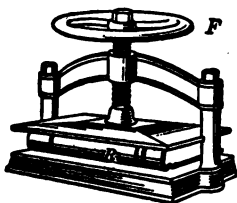


FIG. 94

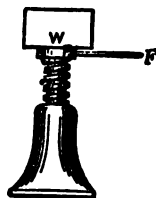


FIG. 95

29. If a force of 20 lb. applied to the circumference of the wheel of the book press, Fig. 94, acts through a distance of 3 ft. in making one complete revolution, and thus causes the screw to move downward $\frac{1}{4}$ in., what will be the resistance overcome at *R*?

30. The lever WF of the jack screw, Fig. 95, is 1 meter in length. If one revolution of the force causes the screw to move upward 1 cm, what resistance will be overcome by a force of 10 kg?

31. The turnbuckle shown in Fig. 90 has 16 threads to the inch. The ends of the rods to which it is threaded are 1 in. apart. How far apart are they after 4 complete turns?

FRICTION

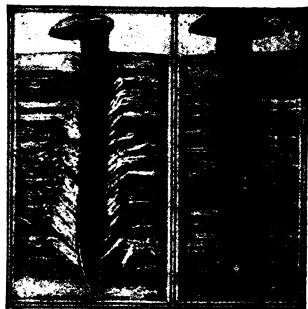
95. **Introductory.** Thus far in our discussion of machines we have neglected to take into account the factor of friction; in other words we have been dealing with ideal simple machines. We shall now consider in a somewhat elementary manner the subject of friction, its laws and uses.

Whenever one body slides or rubs upon another a certain amount of energy is lost through friction. This loss of energy appears mainly as heat. *Friction* is the resisting force which is encountered when one body slides or rolls upon another.

Friction may be classified in various ways. For example, (a) friction between solids and solids; between solids and liquids, as in the case of the passage of a boat through water; and friction between solids and gases, as exemplified by the friction encountered by the passage of an airplane through the air. And again, (b) friction may be classified as static friction, kinetic friction, and rolling friction.

While friction is usually considered as a wasteful factor, so far as the moving parts of a machine are concerned, yet it should be borne in mind that friction under many circumstances plays an important part in mechanical operations, as for example in the driving of pulleys by means of belts, and in the use of the friction clutch in engines. Also, friction has innumerable useful applications in the affairs of every day life. Nails and screws are held in place by friction, we are enabled to walk upon smooth floors and other smooth bodies because of friction. Other illustrations might be cited in great numbers.

Recently some very interesting and important studies have been made with reference to the frictional holding power of railroad ties for spikes, Fig. 96. The old-fashioned wedge-nosed railroad spike, *I*, crushed its way through the wood, breaking the fiber and thus greatly reducing the friction between the wood and the iron. The new spike, *II*, is provided with a spirally fluted shank, which bores its way into the tie as it is driven into the wood. The holding power of spike *II* is over 40 per cent greater than that of *I*.



I *II*
FIG. 96.—Spike *II*, which has a spiral fluted shank, has a holding power over 40 per cent greater than Spike *I*

96. Fundamental Facts Relative to Friction. (a) Friction between two bodies, *A* and *B*, as for example a brick lying upon a smooth plank, is mainly due to the inequalities which occur upon the surfaces of both so-called "smooth" bodies. It is evident that the force required to push or pull *A* over the surface of *B* will depend to a large extent on how closely the irregularities of the surface of *A* fit into those of *B*. It is clear, also, that the greater the force pressing *A* and *B* together (normal force) the more intimate will be the contact between *A* and *B*, and hence the greater will be the frictional force.

(b) It has been found by experiment that, in general, the friction between two substances of like kind is greater than between substances of unlike kind. For example, the friction between steel and steel is greater than between steel and brass. It is for this reason that steel shafts are frequently set to rotate in brass bearings. For the same reason also, "babbitt" bearings are employed, the friction between steel and babbitt being relatively small. Babbitt metal is a soft alloy, extensively used for the linings of axle bearings, in order

to reduce friction; it is an alloy consisting of copper, tin, and antimony.

(c) A common method of reducing friction between the moving parts of a machine involves the use of lubricating oils. In this case we have to deal with the friction between a solid and a liquid (oil), and also between a film of oil on oil. A number of factors enter into a study of friction of this sort, among the most important of which is that of temperature.

97. Static, and Kinetic Friction. The *static friction* between two bodies *A* and *B* is the resisting force which is encountered when the state of *A* is changed from a condition of rest to that of steady motion over *B*. When uniform motion begins the pulling force is just equal and opposite to the static friction.

Kinetic friction is the friction which is encountered when one body slides with constant speed over another. The following fundamental facts have been determined experimentally with reference to kinetic friction.

(a) Through a considerable range kinetic friction is independent of the speed of the moving body. At very high speed, however, the friction is considerably less than for low speed.

(b) Kinetic friction is independent of the area of the moving body, provided the moving body does not cut into the surface upon which it slides. To prove this attach a spring

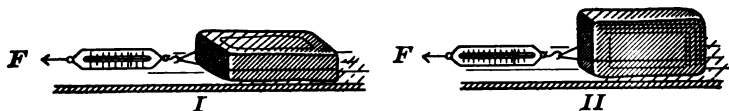


FIG. 97.—Friction independent of area

balance to a brick, the broad surface of which is in contact with the table, as shown in Fig. 97, *I*. By means of the spring balance, draw the brick over the surface of the table with a uniform motion and note the reading of the balance.

Now place the brick with its narrow face in contact with the table, *II*, and draw it along as before. The reading of the balance will be the same as in the first case, thus showing that the friction is independent of the area of the surface in contact.

(c) Kinetic friction is directly proportional to the force with which the surfaces are pressed together. Thus if one brick drawn over the table offers a given resistance, two bricks, one placed upon the other, will offer twice as much resistance (friction).

98. Coefficient of Kinetic Friction. In designing machinery in which moving parts are employed, the engineer has to take into consideration a factor known as the coefficient of friction. Friction coefficients of all ordinary materials are given in tabular form in engineering handbooks.

The *coefficient of kinetic friction* for the substances *A* and *B* is the ratio of the force *F* required to move *A* over *B* at a constant speed, to the normal force *N* pressing the two surfaces together; that is,

$$\text{coefficient of friction} = k = \frac{F}{N}$$

Suppose that we wish to find the coefficient of kinetic friction between iron and leather, as exemplified by the friction between an iron pulley and a leather belt. Place the leather belt on a table in a horizontal position. Place upon the leather a rectangular block of iron, having slightly rounded edges. Suppose that the weight of the iron is (say) 1050 grams (gravitational units). Since the leather surface is horizontal the normal force *N* pressing the iron and leather together is equal to the weight of the iron, hence $N = 1050$ grams of force. Now suppose that a pulling force *F* of 588 grams is required to keep the iron sliding over the leather with constant speed. Then the coefficient of friction in this case is

$$k = \frac{F}{N} = \frac{588}{1050} = 0.56$$

The coefficient of kinetic friction for dry oak on oak, fibres parallel, is 0.48; steel on steel, not lubricated, 0.21; cast iron on brass, dry, 0.19; iron on leather, dry, 0.56; iron on leather, oily, 0.15.

99. Rolling Friction. *Rolling friction* is the friction encountered by a wheel rolling without slipping upon a surface. When a heavy body such as a cylindrical disc or wheel rolls over a given surface there appears a slight elevation or hump in front of the advancing disc. This elevation is very much exaggerated in Fig. 98 for the purpose of illustration. At every instant during its forward motion the wheel is in the act of ascending the elevation.

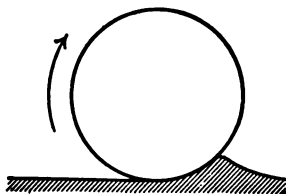


FIG. 98.—Elevation in front of a rolling wheel

Rolling friction, therefore, is measured by the force required to keep the wheel from rolling back. In some cases, as for example, the case of an automobile running over a hard pavement, the deformation occurs in the wheels.



FIG. 99



FIG. 100

Ball and roller bearings

The following facts are known with reference to rolling friction: (a) Rolling friction is very much less than sliding friction. It is for this reason that it is much easier to draw a given load in a wheeled vehicle over a pavement than it is to draw the same load in a sled. For a similar reason, also, ball bearings, Fig. 99, and roller bearings, Fig. 100, are substituted for bearings in which sliding friction occurs.

(b) Rolling friction is inversely proportional to the radius of the wheel. This explains the advantage of using as large a wheel as practicable for a given surface and load.

(c) Rolling friction is proportional to the weight of the rolling system.

GRAPHIC METHODS EMPLOYED IN SCIENTIFIC AND INDUSTRIAL PROCESSES



FIG. 101.—Cyclegraph record of the motions of a man learning to operate a drill press

100. Introductory. In recent years the practice of employing graphic methods in scientific processes and especially in industrial efficiency measurements has been widely extended. For example, (a) the mechanical engineer makes constant use of the "work diagram" in estimating the amount of energy expended per piston stroke of heat engines (both gas and steam); (b) the optical graph method furnishes an admirable method of determining the efficiency of workmen in the various industrial callings, Fig. 101. Also (c) similar methods are employed in the study of motions exerted by

oarsmen, golf players, and so forth, carried out by Mr. M. B. Gilbreth, who made use of an instrument called a *cyclegraph*, Fig. 102. This instrument consists of a small electric light attached to the hand or other moving part of the person or machine under observation. The motion is recorded on an ordinary photographic film or plate. The path of the motion stands out in two dimensions.



FIG. 102.—Cyclegraph

In Fig. 101 there is shown a cyclegraph record of the motions of the hand of a man learning to operate a drill press. In Fig. 103 we have a series of

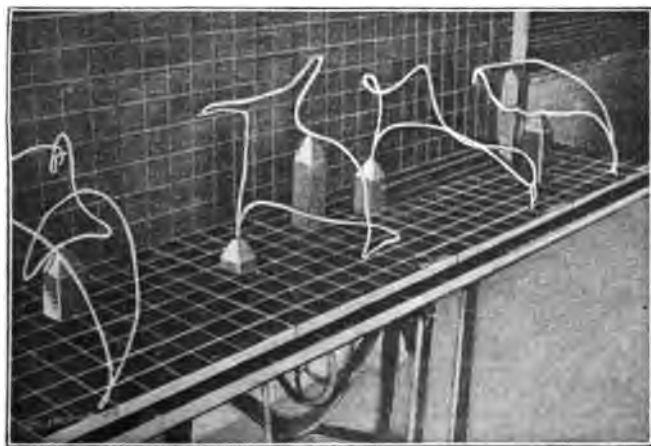


FIG. 103.—Cyclegraph records showing successive steps in operating skill

curves showing the successive steps in operating skill. The cyclegraph record at the left of Fig. 103 illustrates the motions of the beginner in a given technical process; the record reveals

the fact that the operator was irregular and awkward in his motions. The second cyclograph taken after considerable practice shows some improvement, while the record on the extreme right shows decision and skill in operation. Compare the relatively few smooth motions of the skilled worker with the erratic and confused motions of the beginner.

101. The Work Diagram. It is often desirable to represent work graphically by means of the so-called work diagram. Indeed in engineering practice this method is used very extensively. Work is force times space, that is, $W = Fs$. In representing work graphically the displacements s are plotted on the x-axis and the corresponding force values of F on the y-axis of the figure.

When the force is constant the diagram is a rectangle, as shown in Fig. 104. Since work is the product of F and s , it follows that the work done by a constant force F acting through the space s is represented by the area $ABCD$.

If the force varies, as in the case of the expansion of steam against the piston head of a steam engine, the line CD is no

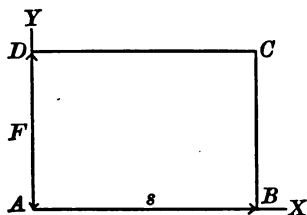


FIG. 104

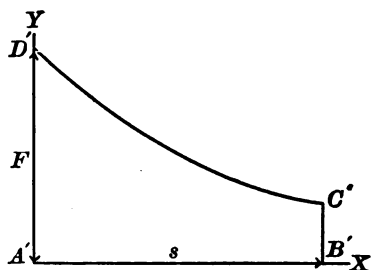


FIG. 105

Work diagrams

longer a straight line but is a curve, as shown in Fig. 105. The area $A'B'C'D'$ again represents the work by the variable (decreasing) force F .

As applied to gas and steam engines, the method of measuring the work done per piston stroke by plotting a force-

space diagram is called the "indicator diagram" method. It was first applied by James Watt.

REVIEW EXERCISES

1. Define: work, power, energy, potential energy, kinetic energy.
2. Define: foot pound, gram centimeter, poundal, erg, joule.
3. Define: watt, kilowatt; define horsepower in terms of (a) watts, (b) foot pounds.
4. Explain the following equations, giving the meaning of each term:

$$W = Fs, P = \frac{w}{t}; P.E. = W = Fs; K.E. = \frac{1}{2}mv^2$$

5. Two men, *A* and *B*, are at work carrying coal into a cellar. *A* carries one ton into the cellar in one hour; *B* carries the same amount in an hour and a quarter. (a) Which man does the greater amount of work? (b) Which works at the greater rate?

6. A weight of 179,040 kilograms is lifted to a height of 10 meters in 2 minutes. Find the rate at which the work is done in (a) watts; (b) kilowatts; (c) horsepower.

7. A stone weighing 2 lb. is thrown upward to a height of 20 ft. At what point does it have (a) its greatest kinetic energy? (b) its greatest potential energy? Explain the relation between the potential energy and the kinetic energy which the stone possesses at any instant during its upward or downward motion.

8. What work, in foot pounds, was done on the stone (problem 7) in order to elevate it to a height of 20 ft.? What is the potential energy when at the highest point? How does the P.E. which it possesses at its highest point compare with the K.E. it will have when it strikes the ground?

9. A body having a mass of 10 grams has a velocity of 5 meters per second. Find its kinetic energy in (a) absolute units; (b) gravitational units.

10. A bullet having a mass of 1 oz. strikes a target with a velocity of 500 ft. per second. What is the K.E. of the bullet in foot pounds?

11. A mass of 10 lb. has a velocity of 5 ft. per second. Find its kinetic energy in (a) absolute units; (b) gravitational units.

12. Define moment of force. What can you say of the moments of a system of forces which are in equilibrium about a given point?

13. Define center of gravity. Locate the center of gravity (a) in a homogeneous rectangular block; (b) circular disc; (c) triangular piece of board.

14. Explain how to find the center of gravity of an unsymmetrical body, such as a piece of board of irregular shape.

15. Define stable, unstable, and neutral equilibrium, and give illustrations of each.

16. In how many ways may the stability of a body be increased? Make drawing to illustrate and explain why a rectangular body lying on its side is more stable than when standing on end.

17. Define line of direction, and explain the relation of this line to the base of a body with reference to its stability.

18. Define: machine, and name the six simple mechanical machines.

19. Define and illustrate: mechanical advantage; efficiency.

20. State the law of machines, and explain each term in the equations $Fs = Rs'$; $Fd = Rd'$.

21. Make drawings to illustrate the three classes of levers, and write a problem applicable to each.

22. Draw three pulleys as shown in Fig. 82 *C* and find what force will be required to support a weight of 600 lb.

23. Draw four pulleys as shown in Fig. 82 *D* and find what force will be required to support a weight of 600 lb.

24. It is desired to lift vertically to a height of 4 ft. a cake of ice weighing 420 lb., by sliding it up a smooth plank used as an inclined plane. (a) Neglecting friction, what force is required to slide the ice up the plane? (b) How much work is done?

25. A man lifts a weight by means of a jack screw, the distance between the threads of which is $\frac{1}{4}$ in.; that is, for every turn of the screw the weight is lifted $\frac{1}{4}$ of an inch. The lever arm of the screw (see Fig. 95) is 3 ft. in length. What weight is the man capable of lifting if he exerts a force of 100 lb.?

26. What is the efficiency of a machine in which a force of 20 lb. moving through a distance of 6 ft. overcomes a resistance equivalent to 48 lb. through a distance of 18 in.?

27. An iron safe weighing 1.25 tons is pulled up heavy skids onto a truck 3 ft. in height by a force of 600 lb. Find the length of the skids, provided friction is not taken into account.

28. A jack screw, having two threads to the inch, is used to lift a weight of 2.5 tons. The force arm (d) of the screw is 2 ft. in length. Find the force required, assuming that the frictional forces are equivalent to 200 lb.

29. In raising a block of granite weighing one and a quarter tons to a height of 80 ft. a hoisting engine did 130,000 foot pounds of useful work. Find the efficiency of the system.

30. Two men, *A* and *B*, carry a load weighing 240 lb. suspended from a bar 6 ft. in length. The weight is 2 ft. from *A*. Neglecting the weight of the bar, find how much of the load each man carries, assuming that the men are located at the ends of the bar.

31. The dimensions of two doors, *A* and *B*, both made of the same material, are 6×10 ft. Door *A* is hinged on the side, and *B* on the end. In which case should the hinges be the stronger, and why?

32. The number of cogs on the gear wheels of the hoisting crane shown in Fig. 106, are as follows: Wheel *A*, 12 cogs; *B*, 48; *C*, 12; and *D*, 60. The radius of the axle of wheel *D* is 2 inches. Wheel *A* meshes into *B*, and *C* into *D*. The length of the crank arm *F* is 18 inches, measured from the center of wheel *A*. (a) Find the mechanical advantage of this machine, taking into account the movable pulley *P*. (b) Neglecting friction, what weight *W* can be lifted by a force of 120 lb.?

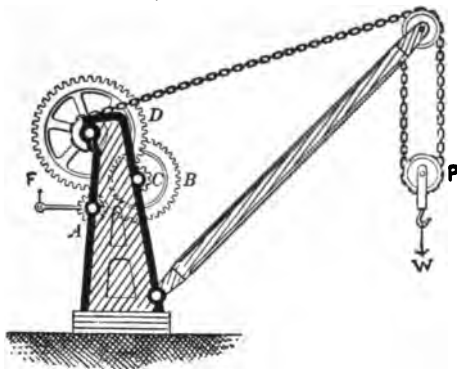


FIG. 106

33. Define: friction, static friction, kinetic friction, rolling friction.

34. State the fundamental facts which are known with reference to kinetic or sliding friction.

35. What is the relation of rolling friction to the radius of the wheel?

36. Define coefficient of friction, and explain each term in the equation $k = F/N$.

CHAPTER IV

MECHANICS OF FLUIDS

PROPERTIES OF FLUIDS

102. Introductory. Matter may be classified in a general way as being made up of solids and fluids. Fluids in turn may be divided into liquids and gases.

A *solid* is a portion of matter possessing both size and shape. A *fluid* is a portion of matter which possesses the property of flowing.

A *liquid* is a fluid, a given mass of which has size but no definite shape; that is, a liquid possesses no definite shape of its own, but conforms to the shape of the containing vessel. A liquid has a definite surface. A *gas* is a fluid which has neither size nor shape. A gas always tends to fill completely the containing vessel. *Vapor* is matter in a gaseous state. Thus when we speak of water vapor in the air we refer to water in a gaseous condition. Mists and fogs, strictly speaking, are not vapors; they consist of collections of small particles of water suspended in the air.

It is very difficult to draw a sharp distinction between certain solids and fluids. Thus water, oil, molasses, pitch, sealing wax are all examples of matter which exhibit in various degrees the characteristic properties of fluids, namely, the tendency to flow. Sealing wax, for example, acts like a solid when struck a sharp blow, in that it breaks like glass; on the other hand it may exhibit the property of a fluid in that it will flow, if time enough is given for the transformation to take place.

Hydrostatics treats of the pressure of liquids at rest. *Hydraulics* treats of liquids in motion. *Pneumatics* treats of the pressure and motion of gases.

Pressure is force per unit of area; that is,

$$P = \frac{F}{A}$$

The student should note that in this text the word pressure is always used to designate force *per unit area*.

103. Properties of Fluids. Fluids possess certain general properties or characteristics which may be stated briefly as follows:

(a) *No statical friction.* Fluids at rest possess no statical friction. When one solid rests upon another there always exists a resisting force (statical friction) which opposes the motion of one surface over the other. In the case of fluids, no such state of friction exists.

(b) *Pressure normal to surface.* The pressure which a fluid at rest exerts against the walls of the containing vessel is always normal (that is, at right angles) to the surface pressed upon.

(c) *Pressure at a point.* Pressure at any point in a fluid at rest is equal in all directions.

(d) *Elasticity perfect.* Fluids possess perfect elasticity. If a force be applied to a fluid confined in a vessel, the volume of the fluid will be diminished; if, however, the compressing force is removed, the fluid will regain exactly its original volume, provided the temperature remains constant. This illustrates what we mean by perfect elasticity.

(e) *Compressibility.* The compressibility of liquids differs very widely in magnitude from that of gases. As is well known, gases are very compressible. Liquids, on the other hand, are almost incompressible. For example, for an increase of pressure of one atmosphere a given volume of air is compressed $\frac{1}{2}$, while a corresponding volume of water is reduced by only $\frac{1}{20,000}$ for the same increase of pressure.

104. Pascal's Law. The law relating to the transmission of pressure by fluids was first definitely stated by Pascal,

a French scientist. Pascal's law may be stated as follows: *Pressure applied to a given area of a fluid enclosed in a vessel*

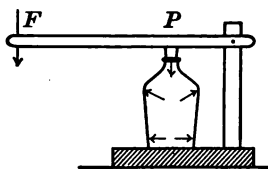


FIG. 107.—Illustrating Pascal's law

is transmitted undiminished to every equal area of the vessel. Pascal performed many striking experiments to demonstrate the application of this law. In one instance he took a long tube and firmly fixed it into the head of a stout cask. Both cask and tube were then filled with water.

The weight of the water in the tube exerted a force on the cask as many times greater than its own weight as the inner area of the cask was greater than the cross sectional area



FIG. 108.—Hydraulic jack used in a testing laboratory exerting a pressure of 90,000 pounds per square inch

of the tube. The force exerted by the water in the tube was sufficient to burst the vessel.

If the force F , Fig. 107, for example, exert a pressure P of 10 pounds per square inch upon the plug which fits tightly into a jug filled with water, the total bursting force which will be sustained by the jug is equal to the interior area of the vessel in square inches multiplied by ten.

105. Hydraulic Press. An important application of the principle stated by Pascal's law is found in the operation of the hydraulic or hydrostatic press. This machine is used when it is necessary to exert enormous force, such as in the compression of material into very small space for economy in shipment, for the lifting of heavy locomotives that have jumped the track, and for the testing of building material, such as re-enforced concrete, Fig. 108.

A sectional outline of a hydraulic press is shown in Fig. 109. The tank A contains a liquid which is driven by the force pump P into the cylinder C , thus acting on the piston P' , driving it upward. The force exerted upon the large piston P' is as many times greater than that exerted on the liquid by the piston P as the cross sectional area of P' is greater than P .

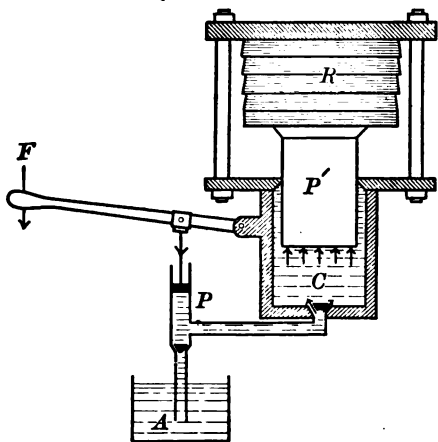


FIG. 109.—Sectional view of a hydraulic press

EXERCISES. 1. Suppose that the cross sectional area of P is 2 sq. in. and that of P' is 200 sq. in. A force of 10 lb. applied to the small piston P will exert what upward force on P' ?

2. A force of 500 lb. is exerted downward upon the small piston of a hydrostatic press, the cross sectional area of the piston being 2 sq. in. This force is transmitted through the liquid to the large cylindrical piston, the diameter of which is one foot. What upward force is exerted upon the large piston?

PRESSURE DUE TO LIQUIDS

106. Pressure in a Liquid. The facts relating to the pressure exerted at any point in a liquid may be stated as follows:

(a) *Pressure in a liquid proportional to the depth.* This can be shown by thrusting a bent glass tube containing mercury down into the water enclosed in a tall glass jar, Fig. 110. As the curved portion of the tube moves downward from *a* to *b*, the mercury is depressed in the arm *c*, due to the increased pressure upon it. If the pressure at a given depth be 10 pounds per square inch, then at twice the depth it will be 20 pounds per square inch, and so on.

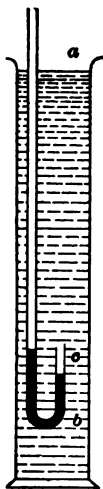


FIG. 110
Pressure pro-
portional to
depth

(b) *Pressure is proportional to the density of the liquid.* Mercury is 13.6 times as heavy as water; therefore, for a given depth, mercury will exert 13.6 times as great a pressure as water.

(c) *Pressure at a point in a given plane is equal in all directions.* This fact may be shown by thrusting three bent tubes containing mercury into a vessel of water, Fig. 111. The lower openings of the tubes are all in the same plane, but communicate with the water in different directions. The depression of the mercury in each tube is the same, showing that the pressure in all directions in the plane *ab* is the same.

107. Force Exerted by a Liquid Upon a Given Surface. The total force exerted by a liquid upon a submerged sur-

face depends upon (a) the area of the surface, (b) the depth of the liquid pressing upon the surface, and (c) the density of the liquid. The total force exerted by a liquid upon an immersed surface is written,

$$F = AHD$$

in which F is the force in gravitational units, A the area of the surface pressed upon, H the height of the surface of the liquid above the *center of area*, and D the density of the liquid. The following table gives the centers of area of some common surface areas:

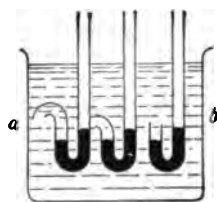


FIG. 111
Pressure equal in
all directions

TABLE XI

CENTERS OF AREA

Figure	Center of Area
Parallelogram.....	intersection of diagonals.
Triangle.....	intersection of median lines.
Circle.....	geometrical center of figure.
Spherical shell.....	center of sphere.
Hemispherical bowl.....	$\frac{3}{8}$ radius, normal to plane surface.
Right cone (hollow).....	$\frac{3}{4}$ distance from vertex to base.

The equation, $F = AHD$, applies to all submerged surfaces, whether vertical, horizontal, or inclined; plane or curved. In elementary physics two cases are, in general, considered.

(a) *Force exerted upon the bottom of a vessel.* The force exerted by a liquid upon the bottom of a vessel having a horizontal base is

$$\text{force} = \text{area of base} \times \text{depth of liquid} \times \text{density of liquid},$$

$$F = AHD$$

(b) *Force exerted upon the side of a vessel.* The force exerted by a liquid upon a vessel having vertical sides varies directly with the depth of the liquid. At the surface the force is

zero; at the bottom it is a maximum. The force has an average value at one-half the depth; hence we may write,

$$\text{force} = \text{area of side} \times \text{one-half height} \times \text{density},$$

$$F = \frac{1}{2} A H D$$

The density of distilled water at 4° C is 1 gram per cubic centimeter; this is equivalent to about 62.4 pounds per cubic foot. In solving problems relating to water pressure it will be assumed, therefore, unless stated specifically to the contrary, that the density of water = 1 gram per cubic centimeter = 62.4 pounds per cubic foot.

EXERCISES. 3. Find the force in grams exerted on the bottom of a cubical vessel 10 cm on each edge, when filled with water.

4. Find the force exerted on the bottom of a cubical vessel 10 ft. on each edge, when filled with water.

5. Find the force exerted on the bottom of a vessel 10 ft. on each edge, when filled with brine, the density of which is 1.2 times that of water.

6. Find the force exerted on the bottom of the vessel mentioned in exercise 3, when filled with mercury, density 13.6.

7. Find the force exerted on one side of the vessel mentioned in (a) exercise 3; (b) exercise 4.

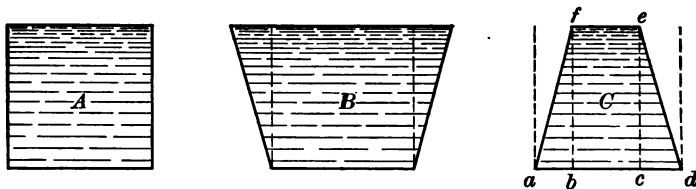


FIG. 112.—Pressure on bottom independent of shape of vessel

108. The Hydrostatic Paradox. We have just learned from the preceding topic that the force exerted by a liquid on the bottom of a vessel depends only on the area of the bottom, the depth of the liquid, and its density. That is, the pressure is independent of the shape of the vessel. This is called the hydrostatic paradox. If three vessels, A, B, C, Fig. 112, having bottoms of the same area, are filled to the same depth

with a given liquid, the downward force exerted on the bottom of each vessel will be the same. In *A* the force on the bottom is equal to the weight of the liquid; in *B* the force is less than the weight of the liquid; in *C* the force is greater than the weight of the liquid. This can be demonstrated by means of three vessels, as shown in Fig. 113. The bottoms of the vessels have equal areas. The tube *T* contains mercury, which stands at the level *cd*. When vessel *A* is screwed upon the standard at *d* and is filled with water, the mercury falls in one arm and rises in the other from *c* to *e*, the height *ce* measuring the downward force at *d*. If now the vessels *B* and *C* be placed successively upon the standard *d* and filled with water to the level *ab*, the mercury in each case will rise to *e* as before, thus showing that the pressure exerted upon the bottom is independent of the shape of the vessel.

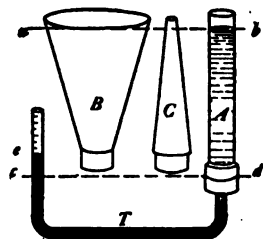


FIG. 113.—Apparatus for illustrating hydrostatic paradox

The explanation of the hydrostatic paradox lies in the statement of Pascal's law; namely, that the pressure exerted upon a given area of the bottom, due to the weight of a column of liquid, is transmitted undiminished to every like area. For example, the pressure exerted by the column *b c e f* of the vessel *C*, Fig. 112, is transmitted to the areas *a b* and *c d*. That is, the force exerted upon the bottom of the vessel *C* is the same as if the sides were vertical.

109. Communicating Tubes. If water be poured into a vessel having two or more communicating tubes, it will rise to the same level in each, no matter what be the shape of the vessel. We say that "water seeks its level." A good illustra-



FIG. 114
Illustrating the fact that water seeks its level

tion of the principle is furnished by the water in a tea kettle or tea pot, Fig. 114. This follows because the pressure is proportional to the depth and is independent of the shape of the vessel. The principle that water will seek its level holds only for liquids at rest.

An application of the principle illustrated by liquids in communicating tubes is sometimes found in the method of supplying towns and cities with water. Where there is no

natural elevated source of supply it is necessary to pump the water into reservoirs or standpipes, situated usually upon high ground, from which it is distributed to the consumers by means of pipes or "mains." The water flowing from a fountain rises theoretically to the level of the source, but practically not so high on account of the friction due to the air and the pipes.

In most large cities the standpipe system is not in use, the water being forced directly into the mains by high pressure pumps.



FIG. 115.—An artesian well such as is common in Northern Michigan districts

110. Artesian Wells. The tendency of water to seek its level is further illustrated by flowing, or artesian wells, Fig. 115. In Fig. 116 there is shown the conditions necessary for such a well. The first stratum is of loose soil; *b* is an impervious layer of clay or rock; *c*, a stratum of gravel; and below this again is another impervious layer, *d*. Water flowing from a height is confined between the two impervious strata *b* and *d* and is under pressure. When the vein of water is tapped,

an artesian well results. An artesian well is usually, but not necessarily, a flowing well; both *A* and *B* are artesian wells.

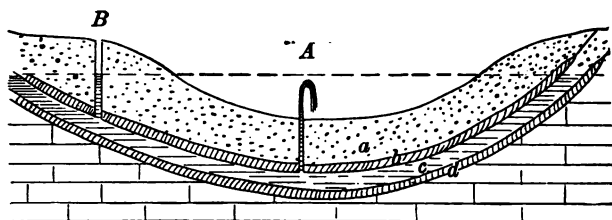


FIG. 116.—Illustrating the pressure system producing artesian wells

The name “artesian” comes from the province of Artois, in France, where the operation of drilling for flowing wells was first performed.

Sometimes these flowing wells occur in comparatively level regions. In such cases the height of the land which furnishes the pressure may lie off at a distance of a number of miles.

111. Water Wheels. One of the oldest methods of obtaining power from water was by means of the water wheel, the old-fashioned and picturesque type of which is familiar to everyone, Fig. 117.

Modern water power plants, Fig. 118, have come to play an extremely important part in the industrial life of the nation. The hydroelectric systems of the West constitute in the aggregate one of the biggest industrial developments this country has ever known. This development is due not only to the demands for power, but to the fact that because of its topography this section of the country is particularly favorable for the generation of electric current on an

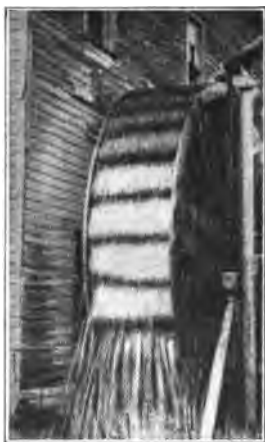


FIG. 117.—Old-fashioned water wheel

extensive scale by means of hydroelectric plants. It is estimated by government experts that out of a total of about 26,000,000 horsepower which it is possible to develop in this way in the entire country, nearly 19,000,000 horsepower lies west of the Rocky Mountains. Conditions for hydroelectric development are particularly favorable in the three states of the Pacific coast where the waters from the melting snows, discharged



FIG. 118.—The Big Meadows Dam, one of the largest dams of its kind in the world

down the precipitous slopes of the high sierras, provide one of the greatest natural resources in the world for the production of electrical energy.

Modern water wheels are of two general types, the water motor and the turbine wheel. The *water motor* is often used in cities where water is delivered in pipes under high pressure. The efficiency of the old-fashioned overshot water wheel was not much above 25 per cent. In a water motor of the Pelton type, on the other hand, an efficiency of over

80 per cent may be attained. In the Pelton motor, water issuing with great velocity from a nozzle is directed against curved blades of the wheel. The high efficiency of this type of water wheel is due to the curved blades which are employed.

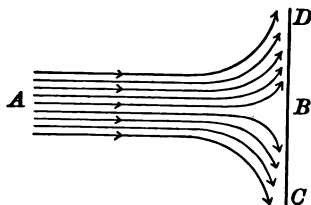


FIG. 119
Force of jet on curved blade twice as great as that on flat blade

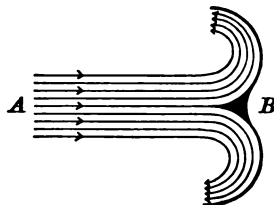


FIG. 120

Let us consider the force which a jet of water exerts when it strikes against a blade of a water wheel. Suppose first that a jet of water be directed against a flat blade, Fig. 119. The direction of the stream is changed from AB to BC and BD .

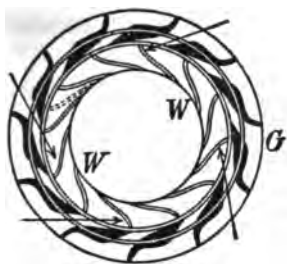


FIG. 121

Turbine water wheel

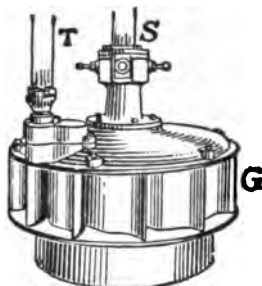


FIG. 122

The momentum of mass m of water having a velocity v is changed from mv to zero. Let the force exerted, which is proportional to the time rate of change of momentum, be F . Now let us consider what happens when the same jet strikes

a curved blade, Fig. 120. The direction of the stream is completely reversed and consequently the change in momentum in this case is twice as great as in the case illustrated by Fig. 119. The force is therefore $2F$. In other words, the force which a jet of water exerts upon a curved blade, as shown in Fig. 120, is theoretically twice as great as that which the same stream would exert upon a flat blade.

The *water turbine* is the type which is now used almost exclusively in large water-power plants. This wheel consists of a system of curved blades, Fig. 121, which are set to rotate in a turbine case, Fig. 122. The amount of water entering the wheel is regulated by the shaft T , by means of which the valves or gates G at the side are opened.

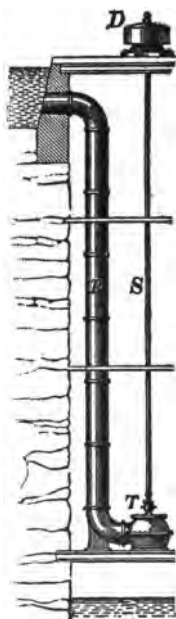


FIG. 123
Hydroelectric
installation at
Niagara Falls

The water turbine in the Niagara hydroelectric plants is placed at the bottom of a turbine pit, Fig. 123, and is connected directly with a dynamo by means of a vertical shaft S . One of the largest turbines in existence is that operated by the Puget Sound Power Company. This plant develops 25,000 horsepower under a head of 440 feet of water.

112. Hydraulic Elevator. An application of the transmission of energy by water power under pressure is found in the hydraulic elevator. There are two common types of such elevators, one of which is shown in Fig. 124, *I*. Here the cage is fastened directly upon a shaft which moves in a deep pit. Passing through the cage is a cord which operates a two-way valve. When c is pulled upward, valve v opens and v' closes, admitting water to the pit from the high pressure main, and thus

causing the elevator to ascend; when c is pulled downward valve v is closed and v' is opened and the water flows from the pit into the waste pipe, allowing the elevator to descend.

The general principle of the operation of a two-way valve is illustrated in Fig. 124, *II*. As the valve is set in the figure, water flows from the elevator shaft through the pipe *H* into the waste pipe *F*. When the arm *D* is moved downward through an angle of 90° , thus rotating valve *E* in a counter-clockwise sense, the openings in the valve *E* connect the pipes *G* and *H*, thus allowing water from the high pressure main *G* to enter the elevator shaft through *H*.

In Fig. 124, *III*, there is shown an elevator of the piston-pulley type. When the piston *P* is forced downward, for example, by the pressure of the water, the elevator cage rises. Since there are four ropes or cables attached to the movable pulley system, it follows that when *P* moves 1 foot the cage will move 4 feet. Thus, if *P* were to move downward 10 feet, the cage would move upward a distance of 40 feet.

113. Hydraulic Mining. One of the earliest methods employed by gold miners for separating the precious metal from the sand and the debris was that known as pan washing. A later method of recovering gold from river beds was that in which the miner made use of a "cradle" or "rocker." In both methods (pan and rocker) the separation of the metal from the sand depended upon the fact that the heavy gold settled to the bottom of the receptacle while the lighter sand and other impurities were washed away.

The construction of great dams and reservoirs in the mountains of the West made possible the washing of finely divided particles of gold from the hillsides by means of the hydraulic process. In Fig. 125, there is shown a "hydraulic giant" washing down the sides of a hill.

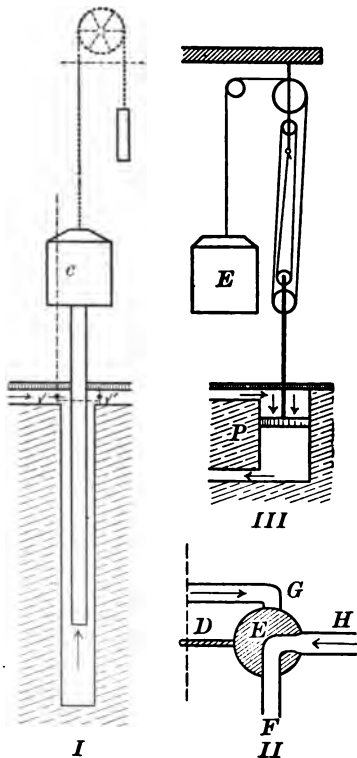


FIG. 124.—Hydraulic elevator

Washing the dirt and boulders out of the way with a jet of water thrown at high velocity from a hydraulic giant is now recognized as one of the most efficient methods for stripping the earth from mineral deposits as well as for many other kinds of heavy excavation. The hydraulic giant consists simply of a tapering metal tube, or nozzle, usually from six to eight feet long, to which water is supplied under high pressure. The nozzle is so mounted that it can be swung both horizontally and vertically, a feature that makes it possible to direct the jet at any point in a relatively large area. The work done by the hydraulic giant in removing the soil depends upon the size of the jet and the pressure under which the water



FIG. 125.—Hydraulic mining

is supplied. When a jet of water is thrown at high velocity from one of these machines it has many of the qualities of a hard rigid bar. In tests made to determine the hardness of jets produced by heavy pressure, attempts to cut through the jet with a sword have simply resulted in the breaking of the blade.

BUOYANCY OF LIQUIDS

114. Archimedes' Principle. If a stone or piece of metal be weighed in air, by means of a spring balance, and then weighed in water, it will be found that the body loses weight in the liquid. It is buoyed up by the liquid in which it is immersed. Archimedes, a Greek philosopher of Syracuse,

Sicily, was the first to announce the principle of buoyancy, which has come to be called the principle of Archimedes, and which may be stated thus: *A body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced*, Fig. 126. According to tradition, the manner in which the principle of buoyancy was discovered was somewhat as follows: Hiero, King of Syracuse, possessed a golden crown which he suspected had been adulterated with a base metal by his goldsmith. He applied to Archimedes to detect the fraud. The solution of the problem was suggested to the philosopher



Archimedes

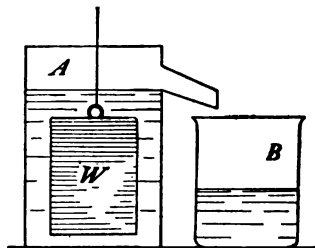


FIG. 126.—A body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced

while he was in one of the public baths of his native city. He observed the buoyant effect of the water upon his body, and conceived that the buoyant force was equal to the weight of the water displaced. He at once perceived that the purity of the crown could be determined by comparing its specific gravity, as determined by the principle of buoyancy, with that of pure gold. Greatly delighted with his discovery Archimedes is said to have exclaimed, "Eureka!" (I have found it!).

115. The Principle Explained. An explanation of Archimedes' principle of buoyancy may be given by means of Fig. 127. Let $abcd$ be one face of a cubical block of unit thickness immersed in water; the downward force acting upon the upper

face of the block is equal to the area cd times the depth cf ; that is, the downward force on the block is equal to the weight of the column of liquid $d c f e$.

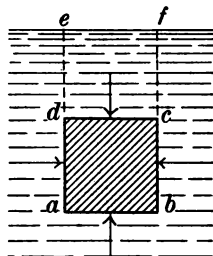


FIG. 127

The upward force acting on the lower face of the block, due to the liquid, is equal to the area of ab times the depth of the liquid bf ; that is, the block is buoyed up by the weight of a column of liquid proportional to $a b f e$. The upward force is therefore greater than the downward force, and the difference between the two, $(a b f e) - (d c f e)$, is equal to the weight of a column of liquid $a b c d$; hence

we say that the block is buoyed up by the weight of the water which it displaces. Whether a body immersed in a fluid will sink or float depends upon the relation between its own weight and the weight of the fluid displaced. If a body be heavier than the fluid displaced, it will sink; if lighter, it will float. If it weighs just as much as the fluid displaced, it tends neither to sink nor float but will remain stationary in the fluid wherever placed.

Archimedes' principle applies equally well to bodies that float as to bodies that sink. A body that floats displaces its own weight; a body that sinks displaces its own volume. The navigation of the modern submarine exemplifies beautifully the principle of buoyancy. The submarine, Fig. 128, is provided with ballast tanks, into which air or water may be forced at the will of the navigator. In order to submerge, the submarine allows water to enter her ballast tanks until the total weight of the boat and contents becomes nearly as great as that of an equal volume of sea water. The boat is then almost submerged. When she is under headway in this condition, a proper use of the diving rudders sends her beneath the surface, or, if submerged, brings her to the surface, so that the lookout can scan the horizon through the

periscope. The whole operation takes but a few seconds. When the submarine wishes to come to the surface for re-

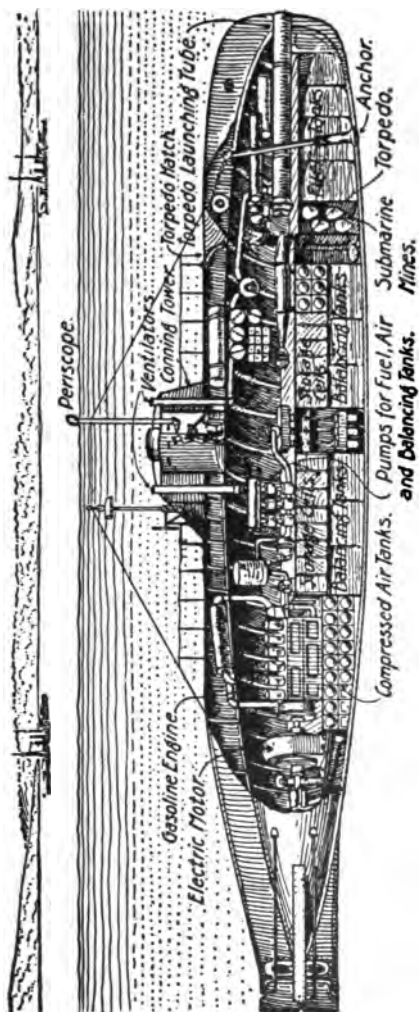


Fig. 128.—Outline section of a modern submarine

charging her batteries or for other purposes, she forces compressed air into her ballast tanks, thus driving the water out of them. Submarines are propelled on the surface by Diesel oil engines, and underneath the surface by storage batteries driving electric motors.

EXERCISES. Note: A cubic centimeter of water weighs 1 g; a cubic foot, 62.4 lb.

8. A piece of metal having a volume of 10 cm^3 , and a mass of 100 grams will displace (a) what volume of water? (b) how many grams of water? (c) Will be buoyed up by what force in water? (d) Will have what weight in water?

9. Let a cubic foot of lead weighing 710 lb. in air be immersed in water. (a) What volume of water will it displace? (b) What weight of water will it displace? (c) With what force will it be buoyed up by the water? (d) It will have what weight in water?

10. A cubic foot of a given substance weighing 60 lb. is thrown into water. (a) Will it sink or float? (b) How many pounds of water will it displace? (c) What will be the buoyant force acting upon it?

116. Center of Buoyancy. Let Fig. 129 represent a cross section of a boat, in which G is the center of gravity of the boat and B is the center of buoyancy. The *center of buoyancy*

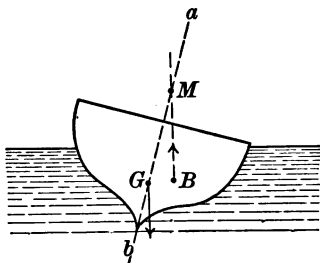


FIG. 129.—Center of gravity below metacenter. The forces of G and B tend to right the boat

of a floating body is the center of volume of the liquid displaced. The point of intersection M of a vertical line through B with the middle line ab through G is called the *metacenter* of the system; that is, M is the metacenter. So long as the metacenter is above the center of gravity G , the action of the two forces is to right the boat; but when the metacenter falls below G , the

action of the two forces is to tip the boat over. When a person stands up in a canoe or row boat, Fig. 130, the effect is to raise the center of gravity G of the system, and thus to

diminish its stability. If by chance the load should be so shifted as to bring the center of gravity G above the meta-center M the boat will overturn.

117. Density. The *density* of a body is its mass per unit volume. This may be written

$$\text{density} = \frac{\text{mass}}{\text{volume}} = D = \frac{M}{V}$$

Density may be expressed in grams per cubic centimeter or in pounds per cubic foot. For example, if 10 cubic centimeters of a given sample of brass have a mass of 80 grams, its density, expressed in metric units, will be $M/V = 80/10 = 8$ grams per cubic centimeter. Likewise, if 2 cubic feet of the same piece of brass have a mass of 1000 pounds its density expressed in English units will be $M/V = 1000/2 = 500$ pounds per cubic foot.

The density of distilled water at 4°C in metric units is 1 gram per cm^3 ; in English units, about 62.4 pounds per ft^3 .

118. Specific Gravity. The *specific gravity* of a body is the ratio of its density to the density of some substance taken as a standard. For solids and liquids the standard is distilled water at 4°C ; for gases the standard is air or oxygen. Since for equal volumes at a given place the densities of two bodies are proportional to their weights, we may define specific gravity as the weight of a body divided by the weight of an equal volume of the standard. Now when a body is weighed in air and weighed in water the loss of weight, according to Archimedes' principle, is exactly equal to the weight of the water displaced, and therefore we may write

$$\text{specific gravity} = \frac{\text{weight of body in air}}{\text{loss of weight in water}}$$



FIG. 130.—A dangerous practice for the novice

Example. The weight of a given mass of brass in air is 20 pounds; weight in water, 17.5 pounds. The loss of weight in water = $20 - 17.5 = 2.5$ lb. The specific gravity, therefore, = $20/2.5 = 8$.

119. Relation of Specific Gravity to Density. Specific gravity is numerically equal to density, *when the latter is expressed in grams per cubic centimeter*. For example, to say that the specific gravity of water is 1 is equivalent to saying that its density is 1 gram per cubic centimeter; and likewise, to say that the specific gravity of gold is 19.3 is equivalent to saying that gold is 19.3 times as heavy as an equal volume of water, which, in turn, is equivalent to saying that 1 cubic centimeter of gold weighs 19.3 grams.

The student should note that density is always expressed in grams per cubic centimeter, or in pounds per cubic foot. Specific gravity on the other hand is a *ratio*; that is, it is an *abstract number*. Since density in grams per cubic centimeter is numerically equal to specific gravity we may write

$$D \text{ in } g/cm^3 = \text{specific gravity} = S.G.$$

EXERCISE. 11. A cubic foot of water weighs 62.4 lb. What is the weight of a cubic foot of gold?

120. How to Find the Density of a Body. (a) If the body be regular in outline, the most direct method of finding its density is to determine its mass by means of a balance and its volume by direct measurement. For example, if a rectangular block 20 centimeters in length, 10 centimeters in width, and 5 centimeters in height have a mass of 5 kilograms, its density will be

$$D = \frac{M}{V} = \frac{5000}{20 \times 10 \times 5} = 5 \text{ g/cm}^3$$

(b) If the body be irregular in outline the simplest method of finding its density is to determine its specific gravity by finding its weight in air and then in water, or in some other

fluid chosen as a standard. As we wish to express density in metric units, and since specific gravity is numerically equal to density in these units, it follows that the specific gravity values thus obtained will be equivalent to the density values in grams per cubic centimeter, that is

$$D \text{ in g/cm}^3 = S.G. = \frac{\text{weight in air}}{\text{loss of weight in water}}$$

(c) Other and special methods will be discussed in the paragraphs which follow.

EXERCISES. 12. If 10 cm³ of lead have a mass of 113 grams, what is its density?

13. If the density of a body having a volume of 24 cm³ is 6 g per cm³, what is its mass?

14. A piece of glass of density 2.6 g per cm³ has a mass of 13 grams. What is its volume?

15. A given piece of iron weighs 225 lb. in air, and an equal volume of water weighs 30 lb. Find (a) the specific gravity of the iron; (b) its density in g/cm³.

121. Density of Solids. (a) *Solids heavier than water.* If the body be of such a form that its volume cannot be readily determined, as in the case of an irregular piece of metal, the method of finding its density is to find its specific gravity. Weigh the body in air, then in water. The loss of weight in water is, according to Archimedes' principle, the weight of water displaced, that is, the weight of an equal volume of water. By means of a beam balance, Fig. 131, determine the specific gravity of the given solid, as illustrated by the following example:

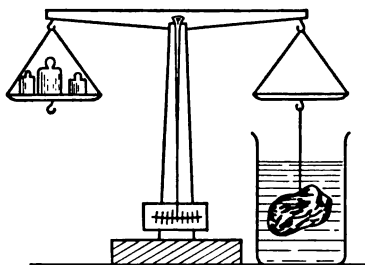


FIG. 131.—A method of determining the density of a solid

Weight of body in air = 10 g

Weight in water = 8 g

Loss of weight in water = 2 g

$$D \text{ in g/cm}^3 = S.G. = \frac{10}{2} = 5$$

(b) *Solids lighter than water.* Suppose that we wish to find the density of a piece of wood, paraffin, or other body lighter than water. Provide a metal sinker sufficiently heavy to sink the given body. Next weigh the given body in air, and then attach the sinker and weigh both in water. The loss of weight of the sinker and body minus the loss of weight of the sinker equals the weight of a volume of water equivalent to the volume of body.

Example. To find the density of a piece of wood.

Weight of sinker in air = 33 g

Weight of sinker in water = 30 g

Loss of weight of sinker = 3 g

Weight of wood in air = 10 g

Weight of wood and sinker in air = 43 g

Weight of wood and sinker in water = 20 g

Loss of weight of wood and sinker = 23 g

Weight of water displaced by wood = 23 - 3 = 20 g

Density of wood = 10/20 = 0.5 g/cm³

(c) *Solids soluble in water.* Weigh the body in air, then in some liquid in which it does not dissolve. Suppose that the liquid chosen is kerosene, the density of which is 0.8 g/cm³. Now since kerosene is lighter than water it is evident that the buoyant effect of kerosene will be less than that of water. Therefore to express the ratio of the weight of the body in air to its loss of weight in kerosene in terms of water, we shall have to multiply by the density of kerosene D' . Thus, we may write, in general

$$D \text{ in g/cm}^3 = \frac{\text{weight in air}}{\text{loss of weight in water}} \times D'$$

where D' is the density in g/cm^3 of the liquid in which the solid is weighed.

Example. To find the density of rock candy. Since all forms of sugar are more or less soluble in water, it will be necessary to select some liquid in which the candy is not soluble, as, for example, kerosene, of density 0.8 g/cm^3 .

Weight of candy in air = 20 g

Weight of candy in kerosene = 10 g

Loss of weight in kerosene = $20 - 10 = 10 \text{ g}$

Density of candy = $(20/10) \times 0.8 = 1.6 \text{ g/cm}^3$

122. Density of Liquids. (a) *Specific gravity bottle method.*

A specific gravity bottle is a small glass bottle having a perforated stopper, Fig. 132. First determine the weight of the empty bottle. Next weigh the bottle filled with distilled water. The difference between these two weights is the weight of a given volume of water. Now fill the bottle with the liquid whose specific gravity is to be found, and weigh as before. Again subtracting the weight of the bottle gives the weight of the liquid. This weight divided by the weight of an equal volume of water is the specific gravity.



FIG. 132
Specific
gravity
bottle

Example. To find the density of glycerine.

Weight of bottle = 15 g

Weight of bottle filled with water = 65 g

Weight of bottle filled with glycerine = 78 g

Density of glycerine = $63/50 = 1.26 \text{ g/cm}^3$.

(b) *Density of a liquid by the sinker method.* Weigh a sinker in air, and then weigh the same sinker in the given liquid; finally weigh the sinker in water. Now since the sinker displaces equal volumes of both the given liquid and of water, it follows that the ratio of the loss of weight in each of the two cases is the specific gravity.

Example. Density of alcohol by the sinker method.

Weight of sinker in air = 20 g

Weight of sinker in alcohol = 18.36 g

Loss of weight in alcohol = 1.64 g

Weight of sinker in water = 18 g

Loss of weight in water = 2 g

Density of alcohol = $1.64/2 = 0.82 \text{ g/cm}^3$

(c) *Density of a liquid by the hydrometer method.* A *hydrometer* is a device for determining the density of a liquid by immersing the instrument in the liquid. If a hydrometer be placed in a jar of water, Fig. 133, the instrument will float in a vertical position, displacing a certain amount of the liquid. Now if the hydrometer be placed in another liquid of greater density, such as a strong solution of salt and water, it will float at a different level. If the instrument be properly calibrated, it will be possible to determine the density of the salt solution directly from the scale. It is evident that a hydrometer with a scale suitable for heavy liquids will not do for light liquids, because the instrument in the latter case would sink to the bottom. Hydrometers, therefore, are calibrated with reference to the use to which they are to be put. A hydrometer calibrated to give the density of milk is called a *lactometer*; to give the density of syrup, a *saccharimeter*; the density of acids, an *acidimeter*, and so forth.

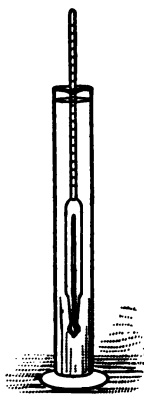


FIG. 133
Hydrometer

EXERCISES. 16. A piece of metal weighs 16 g in air and 14 g in water. What is its density?

17. A stone having a mass of 20 g is dropped into a beaker which is "level full" of water, causing 5 cm^3 of water to flow out. Find the density of the stone.

18. A piece of paraffin, which is lighter than water, weighs 18 g in air. There is attached to the paraffin a sinker which weighs 40 g in

air and 35 g in water. The sinker and paraffin together weigh 33 g in water. Find the density of the paraffin.

19. A sinker weighs 25 g in air and 20 g in water. Find the density of a liquid in which it weighs (a) 23 g; (b) 19 g.

20. A specific gravity bottle when empty weighs 30 g. When filled with water it weighs 70 g; when filled with oil it weighs 60 g. Find the density of the oil.

TABLE XII

DENSITIES IN GRAMS PER CM³

Air, at 0° C. and 76 cm pressure.....	0.00129	Iron, cast.....	7.40
Alcohol.....	0.80	Iron, wrought.....	7.86
Aluminum.....	2.67	Ivory.....	1.82
Antimony.....	6.72	Lead.....	11.30
Beeswax.....	0.96	Magnesium.....	1.75
Bismuth.....	9.82	Marble.....	2.72
Brass.....	8.5	Mercury, at 0° C.....	13.596
Charcoal.....	1.60	Milk.....	1.03
Coal.....	1.3 to 1.80	Nickel.....	8.9
Copper.....	8.9	Olive oil.....	0.92
Cork.....	0.24	Paraffin.....	0.90
Diamond.....	3.53	Platinum.....	21.50
Ether.....	0.74	Silver.....	10.56
German silver.....	8.43	Steel.....	7.82
Glass, crown.....	2.60	Sulphuric acid.....	1.84
Glass, flint.....	3.70	Sulphur.....	2.03
Glycerine.....	1.26	Sugar.....	1.59
Gold.....	19.30	Tin.....	7.29
Granite.....	2.70	Water, at 0° C.....	0.999
Human body.....	0.89	Water, at 4° C.....	1.00
Ice.....	0.92	Water, sea.....	1.03
		Zinc.....	7.00

PRESSURE DUE TO GASES

123. The Atmosphere. The air composing the atmosphere consists of two gases, oxygen (*O*) and nitrogen (*N*) in the ratio by volume of one part *O* to four parts *N*. These gases exist in the air as a mechanical mixture. The most important physical properties of the air are as follows: (a) Air like all fluids is perfectly elastic; (b) it is highly compress-

ible, as illustrated daily in the compression of air in the pumping up of bicycle and automobile tires. Due to this property of compressibility, most of the atmosphere lies very near the surface of the earth. At a height of 3 miles (altitude of Mt. Blanc) the density of the air is only about one-half that at sea level. Men have ascended in balloons to a height of about 7 miles, at which altitude the density was found to be about one-fourth that at sea level. In 1920 Major Schroeder of the United States Army made a record flight in an airplane, ascending to a height of 36,020 feet. At this altitude the temperature was found to be -67° F. The daring aviator was badly frozen, especially about the face, but succeeded in making the descent to earth in safety.

By means of automatic barometers sent up in balloons, it has been possible to explore the atmosphere to a height of some 18 miles. It is estimated that at a height of 35 miles the density of the atmosphere is only about $1/30,000$ of that at the earth's surface. How far beyond this the rarefied atmosphere extends is not definitely known.

124. Air Has Weight. Exhaust the air from a hollow globe by means of an air pump. Suspend this globe from

the arm of a beam balance and counterpoise. Now while the balance is in equilibrium, open the stop cock, admitting air to the globe. It will be found that the globe will appear heavier than before, the balance being out of equilibrium, as shown in Fig. 134. The globe when filled with air weighs more than when empty.

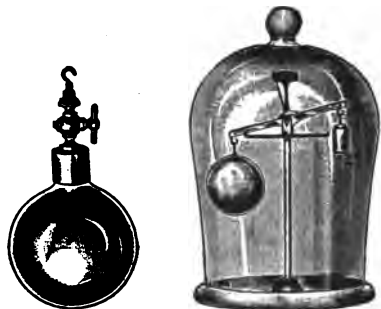


FIG. 134.—Air has weight

The mass of a unit volume of air depends upon the density of the atmosphere, which varies from day to day and from

point to point on the earth's surface. Under standard conditions, that is at sea level, and at a temperature of 0°C (the freezing point of water), the mass of 1 cubic centimeter of air is 0.00129 gram; the mass of 1 cubic foot is 0.08 pound.

125. Rise of Liquids in Tubes. Everyone is familiar with the method of drinking lemonade and sodas by suction through a straw. Of course it is generally known that by "suction" we mean the exhaustion of the air within the tube, thus allowing the pressure of the atmosphere to force the liquid upward. The fact that a liquid is not drawn up by suction but is forced up by the atmospheric pressure was not always known, however, as is illustrated by the story of the Duke of Tuscany's pump. In the days of Galileo, the phenomenon of suction, so called, was explained by saying that "nature abhorred a vacuum." It is related that the Duke of Tuscany, of Florence, Italy, 1640, had a deep well dug on his estate and found, much to his surprise, that the water would not rise in the pump to a height of more than 30 feet. This was a case, as Galileo put it, in which nature seemed to abhor a vacuum only to the height of about 30 feet. Torricelli, a young Italian scientist and a pupil of Galileo, undertook to solve the problem of the mysterious behavior of the water in the Duke's deep well pump.

Torricelli conceived the idea that the reason the water did not rise to a height greater than 30 feet was due to the fact that the pressure of the atmosphere was not great enough to support a column of water beyond this point. He used for his purpose a column of mercury, which being 13.6 times as heavy as water, enabled him to use a tube of convenient length. Torricelli's experiment may be performed as follows: A glass tube about 80 centimeters in length and closed at one end is filled with mercury, Fig. 135. The open end is closed with the finger and the tube inverted; the temporarily closed end is then placed under mercury in the dish and the finger removed. The mercury in the tube falls until the pressure due to the column

of mercury is just sufficient to counterbalance the pressure of the air acting upon the surface of the mercury in the dish. At sea level the mercury column is about 30 inches, or 76

centimeters in height. The space above the mercury in the tube is called a Torricellian vacuum; it contains a small amount of mercury vapor.

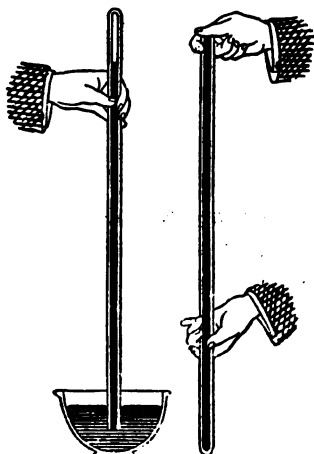


FIG. 135.—Torricelli's experiment

Torricelli concluded from this experiment that air has weight and exerts pressure, and he thus explained the rise of liquids in tubes from which air has been exhausted. This experiment also demonstrated in a satisfactory manner that the failure of the water to rise to the surface in a deep well pump is not due to the presence of an evil spirit, as was thought, but is due to the fact that the pressure of the atmos-

phere is sufficient to support a column of water not greater than 34 feet in height at sea level.

126. Air Pressure Experiments. (a) Atmospheric pressure may be strikingly illustrated by the tumbler experiment, Fig. 136. In this case a tumbler of water having a sheet of paper pressed firmly over the mouth is inverted. The water and paper are held in position by atmospheric pressure.

(b) Into the neck of a flask, Fig. 137, fit a rubber stopper with one hole. Pass through this a short glass tube with the inner end drawn down to a fine opening. Fit one end of a rubber tube to the outer end of the glass tube and connect the other end of the rubber tube to an air pump. Exhaust the air from the flask. Pinch the rubber tube together, and insert the free end below the surface of the water in the dish.

The pressure of the air upon the surface of the water will force a stream through the tube, forming a fountain inside the flask.

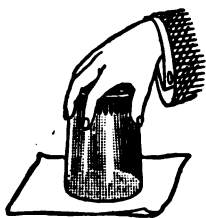


FIG. 136.—Air pressure keeps water in tumbler



FIG. 137.—Fountain in vacuo

(c) The experiment with Magdeburg hemispheres is one of the classics of experimental physics. The two hollow hemispheres, Fig. 138, are pressed together and the air exhausted by means of an air pump. The force holding the hemispheres together is equal to a pressure of 14.7 pounds per square inch of cross sectional area of the sphere through the center.

One of the first to experiment with these hemispheres was Otto von Guericke (1602-1686), a scientist and burgomaster of Magdeburg, Germany. Guericke prepared a pair of hemispheres having a diameter of 22 inches. He then thoroughly exhausted the air and invited the Emperor, Ferdinand II, to witness the pulling apart of the spheres. He hitched horses to each hemisphere, increasing the total number to sixteen before the spheres were pulled apart. In this respect he played a trick upon his wondering auditors, because, as we now well



FIG. 138
Magdeburg
hemispheres



FIG. 139
Standard
barometer

know, and as he no doubt knew, the hemispheres could have been pulled apart by fastening one side of the hitching apparatus to a stake or a tree and the horses to the other side, in which case only eight horses would have been required. The experiment, however, would not have been so striking.

127. The Barometer. The *mercury barometer* is a Torricellian tube fastened to a frame having a scale, by means of which the height of the mercury may be read. If such a barometer be carried up a mountain side the mercurial column will fall, due to the diminished pressure of the atmosphere; if it be taken down into a deep mine or a valley the mercurial column will rise.

A mercury barometer of standard type is shown in Fig. 139. The scale and vernier *V* is adjusted by means of the screw *S*.



FIG. 140
Aneroid barometer

The *aneroid barometer* consists of a metallic box from which a part of the air has been exhausted, Fig. 140. Variations of atmospheric pressure affect the outer case of the instrument, which in turn acts upon a system of levers connected to the

pointers. One of these pointers indicates changes of atmospheric pressure, the other indicates probable changes of the weather, as "Fair," "Change," and so forth. The advantage

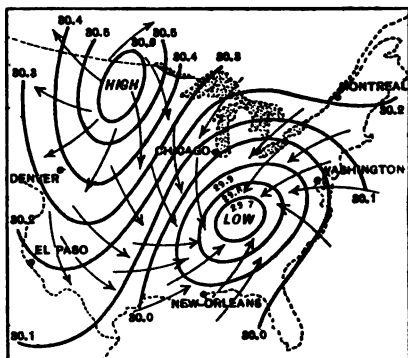
of an aneroid barometer lies in the fact that it is small and is therefore easily handled. It is not so reliable, however, as a mercury barometer, because the mechanical parts of the apparatus are likely to get out of adjustment.

The expression "a pressure of one atmosphere" means the pressure exerted by the atmosphere at sea level and at 0°C (the freezing point of water). Under standard conditions (sea level and 0°C) the height of the barometric column is 76 centimeters, which is equivalent to about 30 inches. A column of mercury 76 centimeters in height and having a cross sectional area of 1 square centimeter has a mass of 1033.3 grams. A pressure of one atmosphere, therefore, is equal to 1033.3 grams per square centimeter, which is equivalent to 14.7 pounds per square inch.

One atmosphere = 76 centimeters of mercury = 14.7 pounds per square inch.

128. Use of the Barometer as a Weather Indicator. Constant use is made of the barometer by the Weather Bureau in forecasting changes in the weather. The relations between

the barometric readings and the direction of the winds may be studied in connection with a weather map. A portion of such a map used by the United States Weather Bureau is shown in Fig. 141. The heavy curved lines, called isobars, are lines passing through places of equal atmospheric pressure. At the place marked *LOW*



"low" region, forming a sort of whirlpool (Art. 151). In the northern hemisphere winds are deflected to the right by the rotation of the earth; hence in the United States the general direction of the wind about these areas of low pressure is counter-clockwise; that is, in the opposite direction to motion of the hands of a clock. If a person stand with his back to the wind, the storm center, that is the region of low barometric pressure will, in general, be on his left hand. The observations of the Weather Bureau on barometric pressure for a series of years indicate that these low pressure areas are continually passing over the country with considerable regularity and along pretty well defined paths. The forecaster depends largely upon his knowledge of the motion of these areas in predicting the weather.

The relation of the barometric reading to the probable condition of the weather may be stated as follows: (a) A rising barometer precedes fair weather; (b) a falling barometer precedes foul weather; (c) a sudden fall in the barometer indicates a storm; (d) a steady barometer indicates settled fair weather.

129. Boyle's Law. If a gas be confined in a cylindrical vessel containing a piston and pressure be applied to the piston, the volume of the gas will be diminished and its density increased. An increase of pressure, then, produces a decrease in volume, if the temperature be constant. The relation between the volume of a gas and the pressure to which it is subjected was first investigated by Boyle. The results obtained were formulated in what is commonly known as Boyle's law, which may be stated thus: *The temperature remaining constant, the volume of a gas varies inversely as the pressure.*

Since the volume decreases in the same ratio as the pressure increases, this law is sometimes written in the form of an equation:

$$pv = c$$

in which p is the pressure to which the gas is subjected, v is its volume, and c is a constant.

Investigation has shown that Boyle's law is only approximately true for all gases. For example, those gases which are easily liquefied, such as carbon dioxide (CO_2), sulphur dioxide (SO_2), and chlorine (Cl), show the greatest variation from Boyle's law. Within moderate limits of pressure, however, Boyle's law is exceedingly useful in the study of gases.

130. Verification of Boyle's Law. Boyle's law and its equation may be verified by means of an apparatus similar to that shown in Fig. 142. To begin with, the mercury stands at the same level in both parts of the apparatus. The air in the chamber C , 20 cubic centimeters, say, is under a pressure of one atmosphere. Now, applying the law we have

$$pv = 1 \times 20 = 20$$

Now suppose that the vessel V be elevated until the pressure upon the enclosed air is 2 atmospheres. The volume is now 10 cubic centimeters and the pressure is 2 atmospheres. Since we have a different pressure and a different volume to deal with, the equation is written

$$p'v' = 2 \times 10 = 20$$

If the pressure be increased to 4 atmospheres the volume will be decreased to 5 cubic centimeters; hence

$$p''v'' = 4 \times 5 = 20$$

It will be noted that in every case the product of the pressure times the volume is the same; in other words, the product of pressure and volume is a constant; that is, $pv = c$, in which in this case $c = 20$.

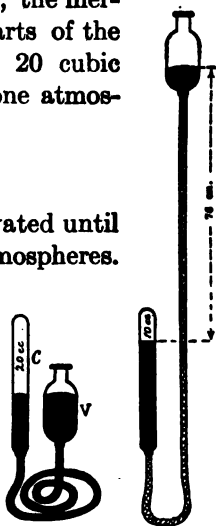


FIG. 142.—Boyle's law apparatus

131. Applications of Air Pressure. *Introductory.* Next to the applications of heat and electricity in the arts and sciences, the applications of air pressure in the commercial and industrial affairs of life are probably more commonly met with than are those of any other phase of physical science. For example, the common cistern pump, as well as all other ordinary pumps, operates because of air pressure; and the same is true of the siphon. Air under high pressure is maintained in garages for the "pumping up" of automobile tires. All modern railroad cars, both passenger coaches and freight trains, are now provided with air brakes. Riveting hammers,

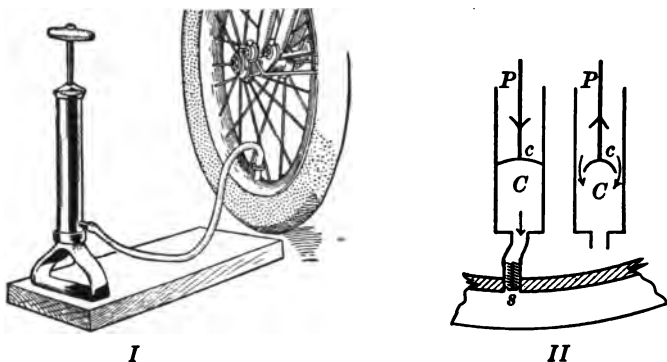


FIG. 143.—Bicycle pump

used in the construction of steel buildings and ships; rock drills, used in mines; pneumatic jacks for lifting heavy loads are all operated by means of air pressure.

We shall begin our study of the applications of air pressure by considering certain types of pumps.

132. The Air Pump. *Bicycle pump.* One of the most familiar examples of an air compressor is that furnished by the common bicycle pump, an outline section of which is shown in Fig. 143. Connected with this pump there are two valves, one, *c*, in the cylinder of the pump and the other, *s*, in the tire, the latter being held in place by a spring. On

the upward stroke of the piston P , valve s in the tire closes, and the cup-shaped piece of leather c allows the air to pass down into the chamber C . On the downward stroke of P the valve c closes and the air is driven into the tire. The bicycle pump is a compressing or condensing pump.

Laboratory air pump. The exhaust pump does not differ in principle from that of the condensing pump. One type of the laboratory air pump is shown in Fig. 144. This is a double cylinder pump the pistons of which make two exhaust-



FIG. 144

Air pump

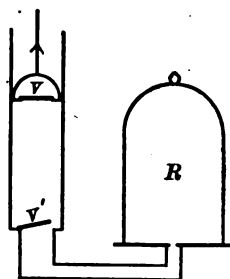


FIG. 145

ing strokes for each revolution of the flywheel. This pump is provided with accurately ground metal valves which are immersed in oil, thus insuring a perfect fit.

The principle upon which the valves of the ordinary air pump work is shown in the outline sketch of Fig. 145. On the downward stroke of the piston, valve v opens, allowing the air in the pump chamber to escape, and valve v' closes. On the upward stroke of the piston v closes and v' opens and air flows from the receiver R .

133. The Mercury Air Pump. A very good mechanical pump will exhaust the air from a vessel until the pressure of



FIG. 146
A simple form
of the mercury
pump

the remaining air in the receiver will support a column of mercury of less than one millimeter in height. In order to get a better vacuum than this it is necessary to use some form of the so-called mercury air pump. These pumps are usually made of glass, mercury playing a part somewhat analogous to that of the piston in the mechanical air pump. The principle upon which the mercury pump operates is shown in Fig. 146. A column of mercury is allowed to fall through a long tube. In passing through chamber *C* it breaks up into drops, each of which serves as a piston to carry a portion of the air downward, thus exhausting the air from *C* and from the attached receiver *R*. As the pressure within the receiver is reduced it is obvious that the mercury will rise in the tube *B*, standing at a height of 76 centimeters when the exhaustion is complete. Pumps of this type are often used in exhausting the air from electric light bulbs.

The most modern type of mercury air pump will produce a vacuum of less than one-millionth of an atmosphere.

134. The Water Jet Pump. The water jet pump or aspirator, Fig. 147, is a form of pump adapted for use where water under high pressure is available, as from the city water supply. A stream of water under pressure enters the tube *a*, which is constricted at the lower end, thus giving a high velocity at *b*. The air is drawn along with the stream of water in the form of small bubbles, thus exhausting the chamber *C*. With a pump of this kind it is possible, with the water from the city mains, to obtain a vacuum of about 5 centimeters of mercury.

EXERCISE. 21. A pressure of one atmosphere is equivalent to a column of mercury 76 cm in height. What atmospheric pressure is represented by a pressure equivalent to 5 cm of mercury?

135. The Ejector. If a strong current of air be blown across the opening of a tube, Fig. 148, the air in the upper part of the tube will be dragged out by the moving column and the pressure within thus reduced. If the lower end of the tube be immersed in a liquid to which the atmosphere has free access, the liquid will be forced to the mouth of the tube, where it is blown into a fine spray. Such an instrument

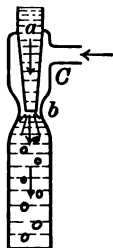


FIG. 147
Water jet pump

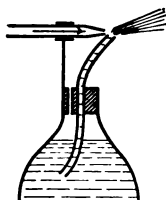


FIG. 148
Atomizer

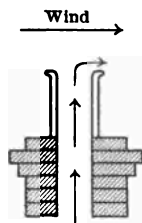


FIG. 149
Ejector principle in
a chimney

is called an ejector. It explains the principle upon which the atomizer works, also the principle employed in the apparatus used so commonly for the spraying of trees and shrubs.

When a strong wind is blowing across the top of the chimney, Fig. 149, the ejector principle comes into play, and a strong upward draft is created in the chimney.

136. The Lift Pump. Shallow well pump. Fig. 150 shows a section of a common cistern pump. The principle upon which it works is illustrated by diagrams, *A* and *B*. The pump contains two valves v and v' , both of which work upward. Diagram *A* illustrates the operation of the valves during a downward stroke of the piston; *B* shows the condition of the valves during the upward stroke. When the pump is first operated, the action of the piston and valves exhausts

the air from the chamber *C*. During this stage it acts as an air pump. The atmospheric pressure upon the surface of the

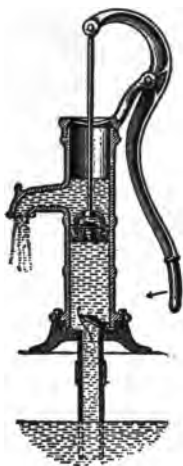
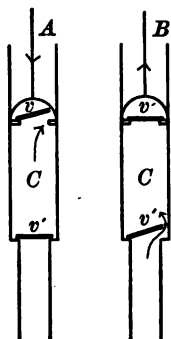


FIG. 150.—The common lift pump



water in the well forces the water up into the pump until both valves become submerged. As the pump continues to operate the valves act exactly as explained in connection with diagrams *A* and *B*.

If the valves of a shallow well pump do not fit closely the water may settle back into the well or cistern, leaving

the valves dry. In such cases it is therefore necessary to "prime" a shallow well pump, that is, wet the valves by pouring water into the pump. The object of priming is to cause the valves to swell sufficiently to exhaust the air from the pump chamber.

Deep-well pump. Since the pressure of the atmosphere is capable of supporting a column of water only about 34 feet in height at sea level, a pump having valves near the surface, as in the case of the ordinary cistern pump, would be of no value in lifting water from a well more than about 30 feet deep. To make a deep-well pump effective it is necessary to place both valves near the water. In the case of a deep well, such as is used in drive wells for example, both valves are usually placed within a few feet of the water, Fig. 151.

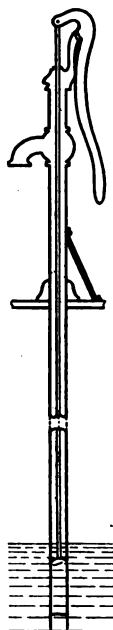


FIG. 151
Deep-well pump

137. The Force Pump. A force pump serves to lift the water from the well and also to deliver it in a steady stream under pressure. In the force pump there is no valve in the plunger P , Fig. 152. The chamber C is partly filled with air. When water is forced into this chamber by the downward stroke of the plunger P , the air in C is compressed; during the upward stroke of P , valve V is closed and the air cushion expands, forcing the water through the delivery pipe in a steady stream.

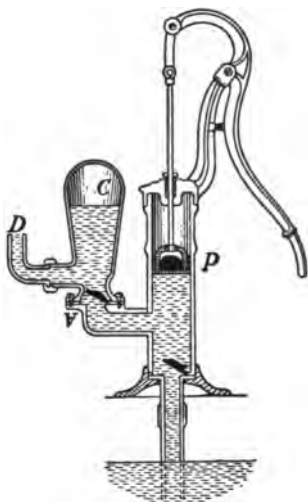


FIG. 152.—Force pump

138. The Siphon. The *siphon* is a device for transferring liquids from a given level to a lower level, over an intervening elevation. It depends for its operation on atmospheric pressure. Fig. 153 shows a siphon in operation. The short arm ab of the siphon is measured from the point of application (surface of the liquid) of atmospheric pressure in vessel A to the highest point of the siphon; the long arm ce , is measured from the highest point to the point of application of atmospheric pressure, as at e .

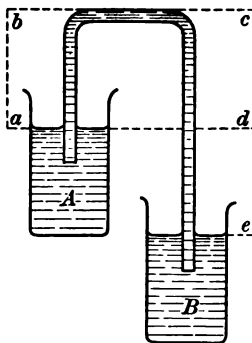


FIG. 153.—The siphon

Action of the siphon. Let W be the pressure of the atmosphere; w the downward pressure due to the weight of the water in arm ab ; w' the downward pressure due to the weight of the water in arm ce . The upward pressure on both arms is that due to the atmosphere,

W . The *effective* upward pressure on the short arm is $W - w$ and the effective upward pressure on the long arm is $W - w'$. Since w' is greater than w , ($w' > w$), it follows that $W - w$ is greater than $W - w'$; that is $W - w > W - w'$. In other words, the greater upward force acts on the short arm, and hence the liquid flows toward the long arm.

Since the pressures (forces per unit area) w and w' are due to the weight of the liquid in the respective arms, $w = hd$ and $w' = h'd'$, where d is the density of the liquid, and h is the height of the column ab , and h' is the height of the column ce . Now if we let P be the effective upward pressure on the short arm, and P' the effective upward pressure on the long arm, then, the net pressure producing the flow is

$$P - P' = (W - hd) - (W - h'd)$$

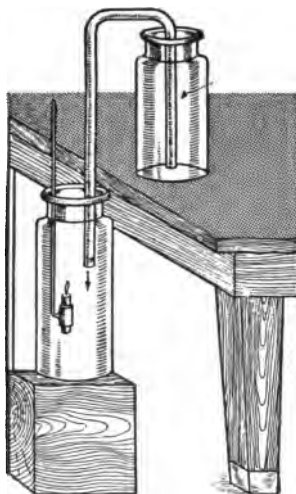


FIG. 154.—Siphoning a heavy gas

A heavy gas such as carbon dioxide (CO_2) may be siphoned from the bottle on the table to the lower bottle, Fig. 154. As the lower bottle fills with CO_2 the candle flame goes out, because this gas is a non-supporter of combustion.

139. The Intermittent Siphon.

In Fig. 155 *I*, there is shown a sectional view of a spring which operates on the principle of the siphon. The flow from such a spring is intermittent, and hence it is known as an "intermittent spring." The principle upon which it works may be demonstrated by means of the intermittent siphon.

Seal a bent tube into a funnel, as shown in Fig. 155 *II*. Pour water slowly into the vessel. When the water rises to

the top of the tube *a* the siphon begins to operate, and continues to flow until the water falls below the opening at *b*. The siphon ceases to flow until the water is again above *a*, when it starts again.

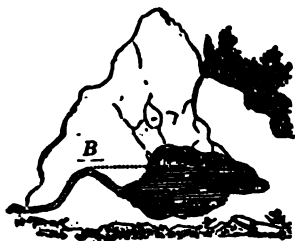
EXERCISES. 22. Will a siphon work in a vacuum? Why?

23. Explain (a) why the flow ceases when the two arms of a siphon are of the same length; (b) why the liquid flows back into the vessel when the outer arm is made shorter than the inner arm.

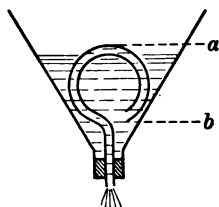
24. Sulphuric acid has a density of 1.84 g/cm^3 , that is, it is 1.84 times as heavy as water. (a) Over what height can sulphuric acid be siphoned? (b) Over what height can kerosene (density 0.8) be siphoned? (c) mercury (density 13.6)?

25. Explain the operation of the intermittent spring, Fig. 155.

140. Household Appliances. In the modern household there are many devices, the operation of which involves either directly or indirectly some form of air pressure appliance.



I



II

FIG. 155.—Intermittent siphon

As a few examples of many which might be mentioned are the pneumatic ink well, the water cooler, the water trap, the air cushion, and others of a similar nature.

The pneumatic ink well. We shall first consider the pneumatic ink well because the principle involved in its operation is the same as that which will be discussed in connection with the study of later appliances. A section of this ink well is shown in Fig. 156. The pressure of the atmosphere upon the surface of the ink in the open neck is counterbalanced by the

weight of the column of ink plus the pressure of the enclosed air in the chamber at the top of the well. When the down-

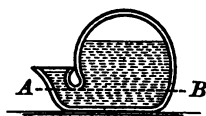


FIG. 156

ward pressure exerted by the ink plus the pressure of the air in the chamber is less than the atmospheric pressure, a bubble of air enters the well, thus forcing more ink down into the neck. As the ink is used, more air enters the vessel. This process continues until the surface of the liquid in the large chamber falls below the line *AB*, when the well should again be filled.

The water cooler. Drinking water is frequently kept in large glass bottles which are uncorked and inverted in a cooling

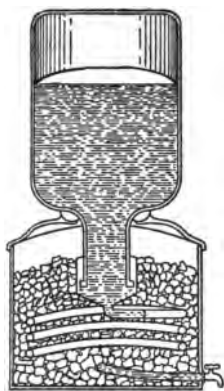


FIG. 157
Water cooler

chamber as shown in outline section in Fig. 157. The cooler contains a tinned coil around which ice is packed. At the lower end of the coil there is a faucet; the upper end terminates in a cup, in which the neck of the inverted water bottle is placed. The pressure of the atmosphere upon the water in the cup holds the column of water in the bottle. When the pressure of water in the bottle plus the pressure of the air above it becomes less than the pressure of the atmosphere, bubbles of air enter the bottle through the open cup, in exactly the same manner as explained in the case of the pneumatic ink well.

The water trap. Water traps are now universally used on drain pipes connected with sinks, water bowls, bath tubs, etc., to prevent sewer gas from entering the house. The water seal or trap consists of a U-shaped tube placed below the bowl, Fig. 158. When the waste water flows out of the bowl, a certain portion remains in the trap, thus forming a seal be-

tween the sewer and the basin. At the bottom of the trap there is a screw head *S*, which may be removed for the purpose of cleaning the pipe when it becomes clogged.

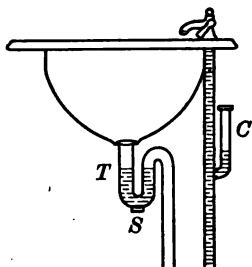


FIG. 158

Water seals

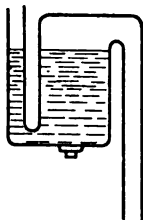


FIG. 159

It sometimes happens that all of the water siphons out of the trap leaving the drain pipe open. To prevent this traps of larger capacity are now frequently installed, Fig. 159.

The drain pipe of the ice box should be provided with a water seal to prevent the cold air of the ice chamber from draining off. This trap consists of a small dish set so that when full of water it will cover the mouth of the drain tube, Fig. 160.

The air cushion. If a faucet through which water is flowing under high pressure be suddenly closed a loud thud of the water in the pipe may be heard. The blow delivered by the water is due to its inertia. Often water pipes are broken and serious damage done due to the force of the impact of the stream when suddenly shut off. To prevent the breaking of pipes and to relieve the force of the blow when sudden changes in pressure occur in water pipes an air cushion is provided, Fig. 161. This is a metal

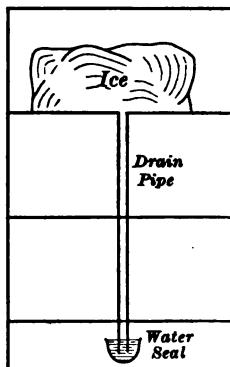


FIG. 160.—Water seal under ice box

pipe or dome filled with air and attached to the water pipe. At every faucet in a city water system such an air cushion is employed. It contains air, which is very compressible. When the tap is suddenly closed the confined air receives and checks gradually the rush of the water in the pipe. Even with an air cushion the "pound" of the water in the pipe when a tap is suddenly closed is often heard.

Two common types of faucets are shown in Fig. 162. Faucet *I* is closed by screwing the plunger down until it closes the opening. The handle of faucet *II* operates a lever arm which opens and closes a horizontal plunger. When the

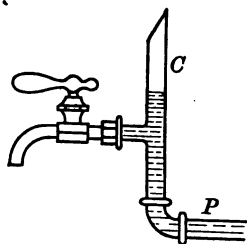


FIG. 161
Air cushion

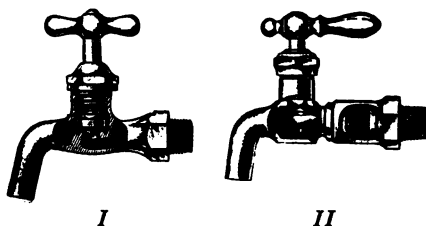


FIG. 162
Water faucets

washer wears out, or the packing comes loose the faucet leaks. Both difficulties may easily be remedied by any one provided with the proper tools.

The vacuum cleaner. The vacuum cleaner is today almost as common an article in the household as the broom and dustpan of our grandmother's time. This apparatus is provided with a suction pump which is driven by a small electric motor. The air, together with the dust and dirt from the carpet, is blown into the attached bag, Fig. 163. The air passes through the walls of the bag, leaving the dust within the receptacle.

141. Commercial and Industrial Appliances. *The wind mill.* The wind mill is in principle a wind turbine, in which

the wind-pressure upon the slanting blades of the power wheel causes it to rotate. When the wind mill is out of commission, that is, when it is not running, the tail piece is turned by means of a lever into a position so that it lies in the plane of the wheel, as shown in Fig. 164; when it is desired to set the



FIG. 163.—Vacuum cleaner



FIG. 164.—Windmill

machine in operation, the tail piece is turned so that it points directly back of the wheel.

The wind mill is employed extensively on American farms for pumping water from deep wells.

The riveting hammer. In modern ship building and in the structural work of the "sky scrapers" of our great cities, steel work is extensively used. The tall white structure shown in Fig. 165, is the Woolworth Building of New York City. This building, which is 57 stories in height, is constructed of steel, concrete, and white tile. In the erection



FIG. 165.—The Woolworth Building at night, New York City. The frame-work of this building is made of steel beams which are firmly riveted together

of buildings of this sort a steel framework forms the supporting part of the structure. The steel beams composing this framework are riveted firmly together, forming when completed practically a solid piece. The countless iron rivets required are driven firmly into place and fastened (riveted) by means of riveting hammers, Fig. 166, which are driven by air pressure. A sectional view of a riveting hammer is given in Fig. 167. The rod marked *A* is the hammer, shown in contact with the rivet; *B* is the piston, which is driven against *A* by air pressure; *C* is a trigger for turning on the air; and *D* is the opening through which the compressed air is admitted.

The rock drill. In Fig. 168 there is

shown two miners at work using a "jack-hammer" rock drill, which is driven by compressed air. With this machine a miner can drill as many holes in an hour as he could in eighteen



FIG. 166.—Riveting steel beams

hours with the old-fashioned hand drill. Holes are drilled into the rock or ore after which powder or dynamite is introduced into them and the rock blasted into relatively small pieces.

Compressed air is used in mines also for other purposes than that of operating drills, as, for example, the coating of the roof and walls with cement by means of a fine spray from a compressed air spray pump or "cement gun." One of the frequent causes of mine cave-ins is the weathering of the slate of the roof and side walls. It gradually crumbles or scales off and suffers a consequent weakening, which may finally bring disaster. The cement gun covers the slate with a thin plaster, which effectually shuts out the air and leaves it as unexposed to deterioration as it was during the countless ages before the coal was removed.



FIG. 167. — Sectional view of riveting hammer



FIG. 168.—Rock drill driven by air pressure



FIG. 169.—Compressed air tamper

Compressed air tampers, Fig. 169, are now used to break up concrete pavements in street improvement work. The pneumatic tamper works on the same principle as the riveting hammer.

The pneumatic jack. Air pressure in the pneumatic jack, Fig. 170, can be used for lifting great weights in a manner exactly similar to that employed in the use of water pressure with the hydraulic press. The pneumatic press or jack is extremely convenient in lifting great weights because of the

comparative ease with which it may be handled. The compressed air jack shown in the cut is capable of lifting a load of 35 tons, one foot high in two minutes.

The Westinghouse air brake. One of the most important commercial applications of compressed air is that employed in the Westinghouse air brake, now used on nearly all steam and



FIG. 170.—Pneumatic jack lifting a load of 35 tons

electric cars. The principle upon which the air brake works is illustrated in the diagram Fig. 171. A compression pump on the engine supplies air to the receiver *R* through the pipe *P* under a pressure of about 70 pounds to the square inch. The receiver *R* connects with the cylinder *C* and with the pipe *P* through a triple valve *V*. When the pressure on *P* falls, due to the operation of the lever by the engineer or motorman, or

was everywhere done by hand. This operation is slow and laborious, and it is not infrequently attended by the possibility of contamination of the milk by dust and germs from the cows and from the hands and clothing of the milker. A more sanitary, efficient, and satisfactory method is that which makes use of vacuum milking machines, Fig. 172, which in recent years have been installed in many of our first-class dairies. The essential feature of a milking machine is an evacuating air pump, which is usually operated by a small gasoline engine, and to which there is connected a long tube. One end of this tube is attached to a vessel for the reception of the milk. This vessel is provided with four tubes, the free ends of which are attached to the udder of the cow. The operation of the air pump evacuates the receiving vessel and the tube system, and the milk is drawn quickly and effectively from the cow.

GAS SUPPLY

142. Natural Gas. The supply of gas to many American cities for heating and cooking purposes is of almost as great importance as that of the supply of electricity. Natural gas occurs in certain parts of Pennsylvania, Ohio, Indiana, Oklahoma, and Texas in connection with coal oil deposits. When the gas "pockets" or underground reservoirs are tapped the natural gas, which is under very high pressure, sometimes rushes out with enormous force. In the early days immense quantities of gas were thus allowed to go to waste, in many cases being burned. In Fig. 173, there is shown the flames of burning natural gas at one of the Pennsylvania wells, the flame in this case rising to a height of 120 feet.

Natural gas is now piped from the wells to service lines and is thence distributed to consumers, or sent to stills where by-products are condensed from it. Gasoline and other useful substances are obtained from natural gas which in former days was allowed to escape and be lost.

143. Artificial Gas. Artificial gas, now used in nearly every American town and city outside of the natural gas belt, is obtained from the distillation of soft coal. Formerly only the gas and coke were used, the by-products being considered waste. Now, however, the by-products of the modern



FIG. 173.—A burning gas well

gas plant are considered to be a source of great profit. The question of by-products, however, touches upon the field of chemistry; we shall, therefore, consider here only the questions of storage and distribution.

The *gas-holder*, Fig. 174, is to the city that uses artificial gas what the reservoir is to a city's water supply. Instead of being located on a hill as is the water reservoir, the gas reservoir is located at the lowest point. Water flows down to the consumers, while gas, which is lighter than air, flows up.

The total floating weight of the holder—the weight which the gas is compelled to lift—may be as great as several hundred tons. This weight presses down on the gas contained in the holder to the extent of a little less than half a pound to the square inch.

The gas is not allowed to enter the distributing mains under this pressure, however. It is reduced or throttled back by governors at the works, giving the consumer gas under a pressure of about one-tenth of a pound per square inch.

Three elements make up the holder: First, the tank, resting

on its concrete foundation and containing several million gallons of water, depending on the size of the tank: then the

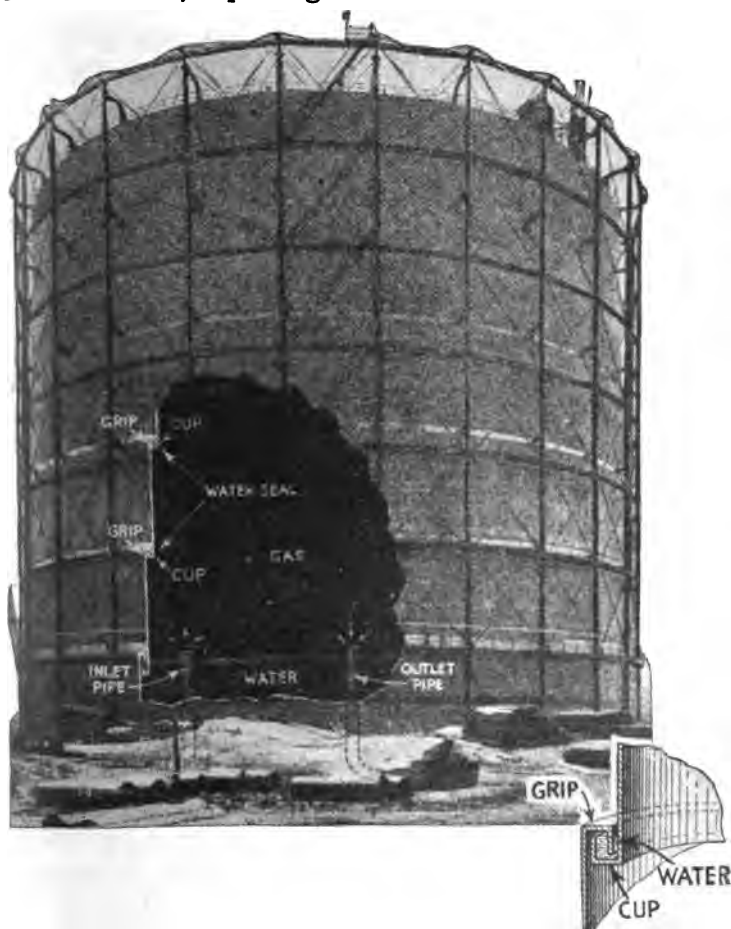


FIG. 174.—Illustration of a large gas holder, showing the guide frame, water tank, and water seals

guide frames secured to the outside of the tank to guide the holder in its movements up and down as gas is let in or out;

and finally the holder itself, which is made up of a number of sections, folding up in the tank like a telescope. When the holder contains no gas, all the sections telescope into the tank and are flush with the top of the tank, which is filled with water. As gas is let into the holder through the inlet pipe, which passes up through the water in the tank, the first or inner section, which carries the roof or crown, is inflated; and when it reaches the top of the tank it picks up the second section by means of what is known as the cup. This cup runs around the whole outside circumference of the holder, forming the bottom edge of each section, just as if the edges were turned over and bent upward to hold water. As each section rises it picks up the grip or inverted cup of the next section, and as each cup is filled with water there is formed what is known as the "water lute," or seal, which prevents the gas from escaping.

When the holder is fully inflated all the sections are lifted with their respective cups filled with water. The lowest edge of the lowest section is considerably below the surface of the water in the tank. This prevents the gas from escaping at the bottom.

144. The Gas Meter. The *gas meter* is a device which operates under the pressure of gas in the city mains, and thus registers automatically in cubic feet the quantity of gas passing through it. It consists essentially of a double bellows, as shown in Fig. 175. Gas enters through the pipe *P* and passes down into chambers *A* and *C*, pushing the bellows to the right. This forces the gas in chambers *B* and *D* out through the delivery pipe *Q*. Now the motion of the bellows to the right causes the valve *V* to move to the left, thus closing the opening into *A* and opening that into *D*. The gas now flows in on the right of valve *V*, and the walls of the bellows move to the left, pushing the gas in *A* and *C* out through the pipe *Q*. When the bellows is moved to the left the valve *V* again slides to the right and the process is repeated. The

valve V connects not only with the bellows, but also with a train of wheels which registers on a set of dials the number of cubic feet of gas consumed.

How to read the gas meter. The small top dial which is marked "Two Feet" is called the "testing circle" and is used in testing the meter. The indication of the hand of the testing circle is ignored in the ordinary reading of the meter.

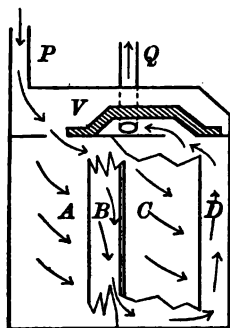


FIG. 175

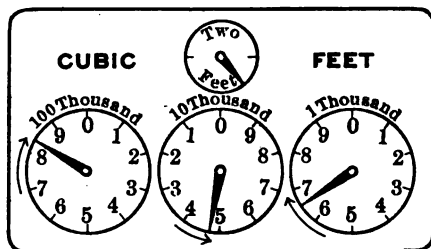


FIG. 176

Gas meter, and recording dials

Note that the hand of the 100 thousand dial and that of the 1 thousand dial rotate in a clockwise sense, while the hand on the middle dial rotates in the opposite sense. To read the meter, begin at the left hand dial and read to the right, noting on each dial the number which was *last passed over* by the hand. Thus, in Fig. 176, the readings are:

100 thousand dial.....80,000 cubic feet

10 thousand dial.....4,000 cubic feet

1 thousand dial.....600 cubic feet

That is, the total number of cubic feet registered by the meter is 84,600.

BUOYANCY OF AIR

145. Buoyancy of the Air. According to Archimedes' principle, bodies immersed in a fluid are buoyed up by a force

equal to the weight of the fluid displaced. Now air is a fluid and it also possesses weight; hence all bodies in air are buoyed up by the weight of the air displaced. The true weight of a body is its weight in a vacuum. In many accurate scientific measurements of mass it is necessary therefore to reduce the values obtained in air to those corresponding to a vacuum.

There is an old saying that "a pound of feathers is heavier than a pound of lead," when weighed in air. This is in a sense true, because of the buoyancy of the air, as can be shown by the following experiment: Counterbalance in air a hollow spherical vessel against a small solid metal sphere, Fig. 177.

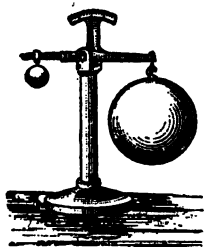


FIG. 177.—Illustrating buoyancy of air

Of course the buoyancy of air upon the large sphere is greater than that upon the small solid sphere. Now place the balance under the receiver of an air pump and exhaust the air. As soon as the air is withdrawn from the receiver and its buoyant effects removed the balance is no longer in equilibrium, the larger sphere now overbalancing the smaller one. Thus the two bodies which apparently had equal masses in air are found to have different masses in a vacuum. The large hollow sphere corresponds to the pound of feathers and the small solid sphere to the pound of lead.

146. The Principle of Buoyancy Applied to the Balloon. A balloon is an air-tight bag, usually made of silk, filled with a gas lighter than air, Fig. 178. The buoyant force tending to elevate the balloon is equal to the weight of air which it displaces. The gas generally used for inflating balloons is either hydrogen or illuminating gas, usually the latter, on account of its comparative cheapness. Under standard conditions a cubic foot of hydrogen has a mass of about 0.006 pound; a cubic foot of illuminating gas, 0.05 pound; a cubic foot of air, 0.08 pound.

Now in order to compare the net buoyant effect acting upon equal volumes of two of these gases, we shall consider the following example: Given two toy balloons of the same volume, one containing a cubic foot of hydrogen and the other a cubic foot of illuminating gas, to find the net buoyant effect on each, neglecting the weight of the balloon in each case. *Solution: The weight of air displaced by each balloon is the same; namely, 0.08 pound. The net buoyant effect in each case will therefore be the difference between the weight of air displaced and the weight of the balloon; that is, (a) for hydrogen the net buoyant effect will be $0.08 - 0.006 = 0.074$ pound per cubic foot; (b) for illuminating gas, $0.08 - 0.05 = 0.03$ pound per cubic foot. Thus we see that the net buoyant force acting upon the hydrogen balloon is about 2.5 times as great as that acting upon a balloon containing illuminating gas.*



FIG. 178
Balloon

147. The Dirigible Balloon. A dirigible balloon consists of a cigar-shaped receptacle for holding the gas, below which is suspended the car for the accommodation of the driving engine and the passengers, Fig. 179. Propulsion is obtained by means of the rotation of fan-like propellers. The modern dirigible is of enormous size and is provided with very powerful engines. The British dirigible R-34, which was the first to cross the Atlantic, arriving in America (Mineola, Long Island) July 6, 1919, had a capacity of 2,000,000 cubic feet, and was provided with five engines giving a total of about 1300 horsepower. The trip was made from Scotland to New York in 108 hours; the return trip was made in 75 hours.

148. The Airplane. Aviation is the art of lifting and propelling through the atmosphere a body heavier than air by utilizing the resistance offered by the air itself to the movement of the body. For centuries man has attempted to

emulate the flight of birds, which are in a sense heavier-than-air machines. The apparatus which he has used in attempting



FIG. 179.—Zeppelin dirigible balloon

to fly may be classified under three heads: (a) Those which are propelled by flapping wings, in imitation of birds; (b)

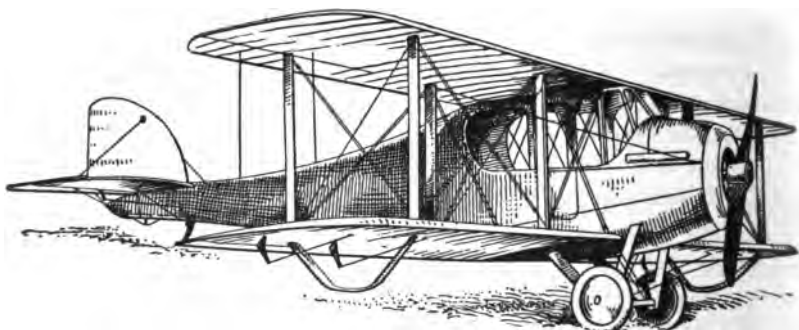


FIG. 180.—Modern commercial airplane of the passenger type

those which depend for their propulsion through the air upon screw-propellers alone; and (c) those which depend for their support upon wing-like surfaces, and for their horizontal motion upon the screw-propeller.

The soaring bird and the flying kite were the natural forerunners of the modern airplane, Fig. 180. The operation of the airplane may be best understood by considering the phenomena of the flying of a kite, Fig. 181. Three forces act upon the kite. One is its weight, acting downward; another is the force c in the cord which keeps it in an oblique position; and the third is the force of the wind, a component of which acts upward upon it. Now the airplane may be regarded as a kite which is self-propelling. As it is driven through the air by means of the rotation of its screw-propeller, the air exerts a force which is sufficient to support it. Like the dirigible balloon it is directed to the right or left, up or down, by means of rudders.

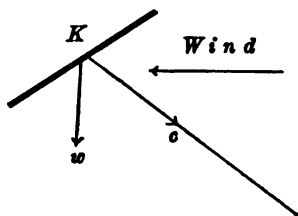


FIG. 181.—The kite

In all trials in which prolonged flights have been accomplished it has been found that a speed of at least 30 to 50 miles an hour is required. Speed is an absolute necessity, for the airplane depends upon its speed for two things: First, its support in the air, and second, its ability to overcome fluctuations in atmospheric currents.

It is worthy of note that navigation of the air by means of the airplane became possible as soon as a light and powerful motor was developed. The light modern gas engine and the airplane appeared almost simultaneously. The problem of successful navigation of the air depends upon the efficiency of the balancing and propelling appliances.

The first non-stop flight across the Atlantic was made on June 14, 1919, by Captain John Alcock and Lieutenant A. W. Brown, of the British army. The flight from Newfoundland to Ireland, a distance of 1890 miles, was made in 15 hours and 57 minutes, the average speed being 118.5 miles per hour. One of the results growing out of the World War was the

extraordinary development of the science and practice of aeronautics. A greater advance in this new field of physical science was made during the four and a half years of the conflict than in all probability would have been made in 25 years had the necessities of war not intervened.

In response to a very actual need of the airplane pilot the U. S. Bureau of Standards has developed a little instrument

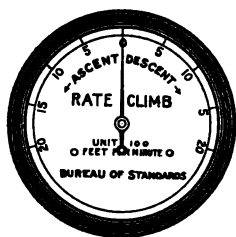


FIG. 182.—Rate-of-climb meter

for measuring the rate of climb of an airplane. This instrument is called a rate-of-climb meter. It involves the leakage of air from the meter as the airplane climbs. In one form of the invention this leakage actuates a pointer on a calibrated dial, Fig. 182. The readings are taken in hundreds of feet per minute.

149. The Motion of the Airplane

Explained. In considering the motion of an airplane several factors have to be taken into account. There is first the weight W of the plane; second, the reaction R offered by the air; third, the angle of incidence which the wings make with the direction of motion; fourth, the area A of the wings; and finally, the velocity v with which the plane moves forward. In the case

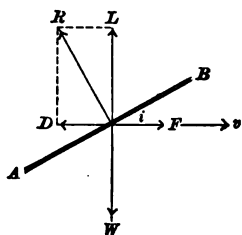


FIG. 183

of an airplane in motion we may consider that the plane is moving through the air or that a stream of air is moving against the plane. Assume that the plane AB , Fig. 183, is moving in the direction from D to F with a velocity v miles per hour. The plane makes an angle i with the direction of motion.

The reaction offered to the tilted wing AB is represented by the force R , which may be resolved into two components L and D . The vertical component L is called the "lift," and the component D is called the wind

resistance or "drag." These components (lift and drag) may be observed by blowing upon a card held oblique to the air stream, or by moving the inclined hand rapidly through water, in which case the upward lift may be distinctly felt. It is the lift L that holds an airplane up in its flight. It has been found in practice that better lift is obtained from a "cambered" wing than from a flat one. A cambered wing is one that is slightly curved from front to back.

We wish to consider now the problem of horizontal flight, ascent, and descent under power. When an airplane with power shut off descends without acceleration or rotation it is said to *glide*. We shall not consider here the problem of gliding.

Two of the fundamental equations of motion of the airplane are

$$\begin{aligned} D &= K_d A v^2, \text{ and} \\ L &= K_l A v^2 \end{aligned}$$

in which D is the drag, L the lift, A the area of the wings, v the velocity, and the factors K_d and K_l the coefficients of drag and lift respectively. The values of these coefficients depend upon the angle of incidence i . It is evident then that when the angle of incidence is changed the coefficients are changed, and consequently the drag D and the lift L are changed.

Now in order to have forward motion it is clear that the "thrust" or pulling force F due to the propeller must be as great as the drag D ; that is for forward motion $F = D = K_d A v^2$. Let us consider now the three types of motion mentioned, namely, horizontal motion, rise or ascent, descent.

(a) *Horizontal motion*. The problem of securing horizontal flight is simply a problem of securing a lift L equal and opposite to the weight W . In other words the angle of incidence for a given plane must be such that $K_l A v^2 = L = W$. This is the condition for horizontal flight. (b) *Ascent*. Now if the wings be tilted so that the angle of incidence i be made greater

than that necessary for horizontal flight, then the coefficient of lift is increased and consequently L becomes greater than W , and the plane rises. (c) *Descent*. On the other hand, if the value of i be made less than that necessary for horizontal flight the lift L becomes less than the weight W and the plane descends.

FLUIDS IN MOTION

150. Measurement of Flowage. A study of the measurement of the flowage of water is of great theoretical and practical importance, as for example, in the flowage of streams with reference to the construction of power plants, the delivery of water to farms in irrigation districts, and especially, in the consumption of water by households. Water is a commodity the consumption of which involves millions of gallons, and since the installation of water meters is becoming common in towns as well as cities, it is important that consumers become familiar with the measuring device.

The water meter. When not sold by the flat rate, water is usually sold at so many cents per thousand gallons, and the quantity used by each consumer is measured by a water meter. The meter is connected with the supply line from the water main in such a way that no water can reach the consumer without passing through the meter, and all water flowing through the meter is recorded, whether used or wasted through leakage or otherwise.

The principle upon which the water meter works is somewhat similar to that of the gas meter (Art. 144). There are several types of meters in use, the commonest being that known as the "disc" type, Fig. 184, in which the recording mechanism is connected to a disc which is supported at its center on a large ball and which tilts about on its edge as the water passes through the chamber.

Water meters are provided with two types of recording systems. The first is a direct reading record, which is very

convenient to read. The second consists of a series of dials set as in Fig. 185. In reading the dials of the water meter, as in the case of the gas meter, one should note the direction in which the hand of each dial rotates, and should read for each dial the figure last passed over by the hand. The reading of the dials of Fig. 185 is 11,867 cubic feet.

In order to determine the amount of water which has passed through the meter in a given time it is necessary to subtract the initial reading from the final reading. For example, if



FIG. 184.—Section of a "rocking valve" water meter

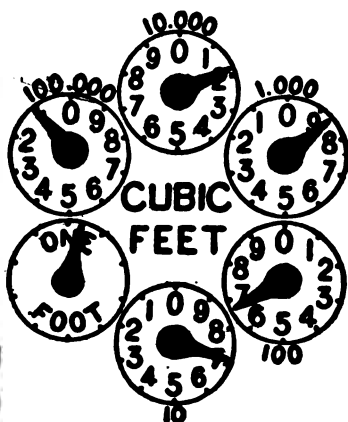


FIG. 185.—Recording dials of a water meter

the meter were read on June 30 and again on July 30, the difference between the two readings is the record for July.

151. Circulatory Motion of the Air. Few fluid motions are of greater importance to us than those of the air. Especially is this true of what is known to the meteorologist as "cyclones," those immense whirls of air many miles in diameter, which give rise to the varying conditions of the "weather." The air being heated at a given point gives rise to a diminished barometric pressure, known as a low region, which together with the motion imparted to the air due to the rotation of

the earth on its axis, gives rise to the cyclonic storms which pass periodically over the country from west to east. In the northern hemisphere these wind storms always rotate in a counter-clockwise sense.

An explanation of this counter-clockwise rotation may be given as follows: Consider the three points a , t , c , on a meridian

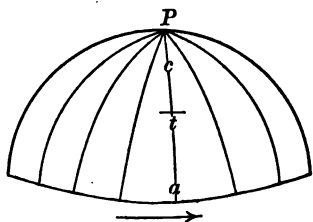


FIG. 186.—Explanation of cyclonic motion of air

ian of the hemisphere, Fig. 186, which rotates about a vertical axis through P in the sense indicated by the arrow. Suppose that t is a target, pivoted so as to rotate about its center, and that guns situated at a and c are aimed directly at its center. Considering the motion of the sphere we wish to find where

the balls fired from the guns will strike the target, with reference to its center. All three points move in the same direction and sense, but with different speeds.

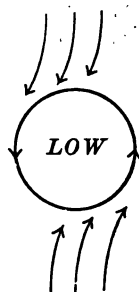


FIG. 187
Circular motion of the air in "low" area

Now it is clear that the speed of a is greater than that of t , and hence the ball fired from a will strike t to the right of the center of the target. Likewise, the speed of c is less than that of t , and therefore the ball from c will strike t to the left of the center, assuming that we are looking from a toward the pole P . This means that the target t will rotate about its center in a counter-clockwise sense. Let us now imagine that the region about t is a place of low atmospheric pressure, and instead of balls fired from a and c , the cold heavy air rushes in, Fig. 187. The air moving upward will be

deflected to the right due to the rotation of the earth, and the air moving downward will be deflected to the left, thus giving rise to a circulatory motion in the low region in a counter-

clockwise sense. It is in this manner that cyclonic rotations of the air originate.

152. Flow of Liquids in Pipes of Variable Section. Consider water flowing in a pipe of variable cross-section, as shown in Fig. 188. It may be shown mathematically, as well as experimentally, that as the velocity approaches a maximum in the constricted portion of the tube, the pressure approaches a minimum. This means that the pressure p is less than that of p' and p'' ; that is, $p < p'$ and $p < p''$. In other words, when a fluid in motion is constricted at any point so that there is an increase in velocity, the lateral pressure at that point in the fluid is diminished. This principle has an important application in the operation of the "Venturi"

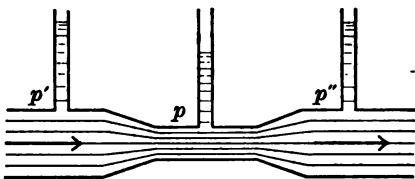


FIG. 188.—The pressure is least where the velocity is greatest

water meter, a modification of which is employed in measuring the water passing through the great Croton aqueduct, which supplies New York City. This principle may also be used to explain the operation of the jet pump, the atomizer or spraying machine, "card and tube" experiment, and the "curving" of a pitched baseball.

153. Card and Tube Experiment.

If air be blown through a tube having a flaring lip ab , and a card C be placed against the lower opening, as shown in Fig. 189, it will be found that the card cannot be blown from the tube, even if the tube be held in a vertical position. This phenomenon may be explained in terms of

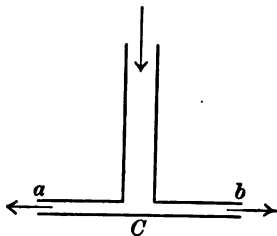


FIG. 189. — Card-and-tube experiment

the principle of diminished pressure as illustrated in the case of the flow of water in a constricted pipe, Fig. 188. The air

passing downward through the tube issues with high velocity through the narrow opening between the card and the flaring lip *ab*. As the velocity of the air increases its lateral pressure diminishes. The pressure of the atmosphere upon the bottom therefore holds it in place.

154. The Curving of a Pitched Ball. To every boy interested in baseball there has occurred the question, Why does a pitched ball curve? The answer to this question involves the principle just discussed in Arts. 152-153, namely the principle of diminished lateral pressure with increase in velocity.

Consider Fig. 190. Here we have illustrated the various motions of a pitched ball. The line *ARB* represents the general direction and sense in which the ball is moving at a given instant after leaving the hand of the pitcher. Two motions are imparted to it by the pitcher, one in the direction *AB*, that is, toward the batter and the other a rotary motion *R*, in a clockwise sense.

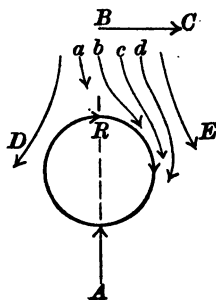


FIG. 190.—Curving of a pitched ball.

We may consider the ball as moving against the air, or, on the other hand, we may consider the air as moving against the ball with a speed represented by the lines *D* and *E*. As the ball rotates it carries air around with it as shown by the lines *abcd*. The velocity of the air on the *E*-side is greater than on the *D*-side, and therefore the lateral pressure of the air against the ball is less at *E* than at *D*. As the ball moves forward it, therefore, curves in the direction *BC*; that is to say, the ball curves in the direction in which it rotates.

REVIEW EXERCISES

1. Define: fluid, liquid, gas, vapor, hydrostatics, hydraulics, pneumatics.
2. What can you say of (a) statical friction in fluids? (b) pressure

with reference to a given surface of the containing vessel? (c) pressure at any point in a fluid? (d) elasticity of fluids?

3. What is meant by perfect elasticity in fluids?

4. State Pascal's law.

5. By means of a sketch describe the hydraulic press.

6. A tube having a cross-section of 2 sq. in. is fitted into the top of a cask, which has a total area of 10 sq. ft. The cask and tube are filled with water. The force exerted by the water in the tube is 10 lb. per sq. in. Find the total force exerted on the interior surface of the cask due to the water in the tube.

7. The diameter of the small piston of a hydraulic press is 1 in.; the diameter of the large piston, 1 ft. (a) What is the ratio of the areas of the two pistons? (b) A force of 10 lb. on the small piston will exert what upward force on the large piston?

8. Give the use of the following equation, and explain each term:
 $F = AHD$.

9. A rectangular vessel, height 10 cm, width 20 cm, length 30 cm, is filled with water. Find (a) the force exerted on the bottom; (b) the force exerted on one end; (c) one side.

10. A cylindrical vessel, radius 10 cm, height 20 cm, is filled with water. Find the force exerted on the bottom due to the weight of the liquid.

11. The cylindrical vessel of problem 10 is filled with water, tightly covered, and then placed on its side in a horizontal position. Find the force exerted by the water on one end.

12. Make sketch to illustrate the principle governing artesian wells.

13. Describe the Pelton water wheel. To what feature does this wheel owe its high efficiency?

14. State and illustrate Archimedes' principle.

15. What is buoyancy as applied to fluids? Define center of buoyancy, metacenter.

16. By means of a sketch explain the relation between center of gravity, center of buoyancy, metacenter, and the stability of a boat.

17. Define: (a) density, specific gravity. (b) Explain each term in the equation $D = M/V$.

18. Explain carefully the relation between density and specific gravity.

19. A given substance having a volume of 10 cm³, has a mass of 15 g. (a) How many grams of water will it displace when submerged? (b) Will it sink or float, and why?

20. A cubic foot of a given substance weighing 50 lb. is thrust under water. (a) What weight of water does it displace? (b) What is the

buoyant force acting upon it? (c) What force must be exerted upon it in order to keep it under water?

21. A rectangular piece of aluminum, $2 \times 4 \times 5$ cm, has a density of 2.6 g/cm^3 . Find its mass.

22. A metallic cylinder having a radius of 2 cm and a height of 5 cm has a mass of 628.32 g. Find its density.

23. A sphere having a radius of 2 cm has a mass of 150 g. Find its density.

24. A piece of metal weighs 14 lb. in air and 12 lb. in water. (a) What is its specific gravity? (b) its density?

25. A small metal ball weighs 20 g in air, 18 g in water, and 17 g in a given liquid. Find the density of the given liquid.

26. The density of lead is 11.3 g/cm^3 . (a) What is its specific gravity? (b) What is the weight of a cu. ft. of lead?

27. A specific gravity bottle weighs 25 g. When filled with water it weighs 65 g. When filled with a given salt solution it weighs 75 g. Find the density of the salt solution.

28. What is a hydrometer, and how is it used?

29. A live fish weighing 2 lb. is placed in a pail of water. Will the pail and contents (water and fish) weigh more than before the fish was placed in the pail?

30. A ship sails from the Hudson River into the Atlantic Ocean. What change takes place with reference to the depth to which the vessel sinks as it enters the ocean? Why?

31. A hollow copper sphere weighs 600 g. What must be the least volume of the sphere in order that it will just float in water?

32. Explain the construction and use of a barometer.

33. When the barometric column stands at a height of 74 cm, what is the pressure of the atmosphere in (a) grams per cm^2 ? (b) dynes per cm^2 ? (c) pounds per in^2 ?

34. State Boyle's law.

35. A given mass of air under a pressure of 400 grams per cm^2 has a volume of 100 cm^3 . If the pressure be increased to 600 grams per cm^2 , what will be its volume, the temperature remaining constant?

36. How will the density of the air (problem 35) be affected by the increased pressure, and how much?

37. Make sketch to illustrate the operation (a) of a lift pump; (b) of a force pump.

38. By means of a sketch explain the operation of the siphon.

39. (a) When the pressure is one atmosphere, over what height may water be siphoned? (b) When the barometric pressure is 70 cm, over what height may water be siphoned?

40. Read the index of the gas meter shown in Fig. 191.

41. A sphere having a volume of 100 cm³ weighs 1 kilogram in air. What is its weight in a vacuum?

42. A block containing 2 cu. ft. weighs 100 lb. in air. What is its weight, referred to a vacuum?

43. A balloon has a volume of 60,000 cu. ft. It is filled with illuminating gas. Find (a) the weight of the illuminating gas in the balloon.

(b) The buoyant force on the balloon due to the weight of the air displaced.

44. Explain the circulatory motion of the air in regions of low atmospheric pressure.

45. A fluid flows through a tube having a constricted portion. (a) What can you say of the velocity of the fluid in the constricted portion? (b) the lateral pressure?

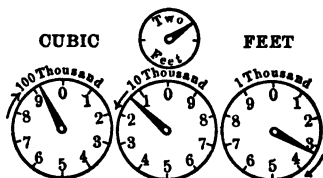


FIG. 191

CHAPTER V

MOLECULAR MECHANICS

SOME SPECIAL PROPERTIES OF MATTER

155. The Structure of Matter. According to present theories matter is composed of small particles which are in constant motion. These particles, which are so small as to be invisible under the most powerful microscope, do not rest one upon the other, as do bricks in a wall, but are constantly striking against each other, bounding back and forth with great rapidity. In view of this theory, the question at once arises, How does matter retain its form? If the particles of a piece of chalk, for example, are in constant motion, how does the chalk retain its shape? The ancients supposed that the particles of which matter is composed were held together by hooks or claws; we of today assume that they are held together by invisible forces which allow considerable freedom of motion, yet which restrain the particles within the form of the body.

The particles of which we have just been speaking are called molecules. A *molecule* is the smallest particle of a substance that can exist by itself and retain its identity. Thus, a molecule of water is the smallest particle that can exist as water. A glass of water is composed of many drops; each drop may be divided into smaller and smaller parts until, it may be conceived, we come to the smallest particle that can exist as water. This is the molecule. If we carry the division further, as may be done by chemical means, we no longer have water, but two gases, hydrogen and oxygen. Molecules, then, are made up of still smaller particles called *atoms*. Thus, a molecule of water contains two atoms of hydrogen and one of oxygen.

And further, there are many reasons which lead modern scientists to believe that atoms, in turn, may be made up

of still smaller electrically charged particles called corpuscles or *electrons*.

156. Chemical Symbols. The chemical symbol for a molecule of water is H_2O . This means that a molecule of water contains two atoms of hydrogen (H) and one atom of oxygen (O). A molecule of common table salt, sodium chloride, is written $NaCl$; that is, the molecule is made up of one atom of sodium (Na) and one atom of chlorine (Cl). In a like manner sulphuric acid is written H_2SO_4 , where S stands for sulphur.

EXERCISE. 1. (a) How many atoms of hydrogen are contained in a molecule of sulphuric acid? (b) How many atoms of sulphur? (c) Of oxygen? (d) How many atoms in the molecule?

157. Properties of Matter Due to Molecular Forces. The properties of a substance are those characteristics which enable us to distinguish it from other substances. *Brittleness*, for example, is a property of glass; *hardness* is a property of the diamond; *tenacity* is a property of iron. There are a great many such properties, among the most important of which are those due to molecular forces. The relation of the properties of a substance to the forces operating between its molecules is very well illustrated in the case of glass. If a glass rod be bent even a very little it will break. We say it is brittle. If, however, the rod be heated in a flame for a few minutes it will bend very readily. It has lost its property of brittleness and now has the property of flexibility.

In the following topics we shall consider a number of properties of matter which are due mainly to the action of molecular forces.

158. Cohesion and Adhesion. The attraction which exists between molecules of the same kind is called *cohesion*. Attraction between molecules of unlike kind is called *adhesion*. The particles of a piece of chalk are held together by cohesion. On the other hand, when crayon is drawn across the black-

board, a chalk mark is made; the attraction between the chalk and the board is due to adhesion.

If a piece of chalk be broken, the parts cannot be united again by pressing them together because the molecules cannot be brought into close enough contact for the molecular forces to operate. If two pieces of lead, however, are forced together by a twisting motion, the parts will cohere.

159. Examples of Molecular Attraction. A broken plate can be mended by means of cement, a kind of porcelain in a liquid condition, which permits of the molecules being brought into intimate contact. The blacksmith unites two pieces of iron by first heating them red hot and then welding (hammering) them together. The hammering is done for two purposes, (a) to force the molecules into intimate contact, and (b) to give the iron the desired shape.

If a clean glass rod be thrust into water and then withdrawn it will be found that a drop of water clings to the glass.

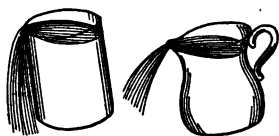


FIG. 192
Illustrating adhesion

In like manner a glass plate clings to water. This means that the attraction of water for glass (adhesion) is greater than the attraction of water for water (cohesion). On pouring water from a glass or pitcher, the tendency of the liquid

to adhere to the glass and to flow free from the spout of the pitcher is well illustrated in Fig. 192.

160. Malleability. *Malleability* is that property of matter by virtue of which a substance may be beaten out into thin sheets. A good example of a malleable substance is the tin foil which is wrapped around many articles displayed for sale in stores. This foil is made by hammering or rolling the metal tin out into very thin sheets. A distinction here must be made between the metal tin and the so-called "tin" of tinware. The material of which a tin cup, for example, is made is really sheet iron coated with a very thin covering of tin.

Gold is one of the most malleable of metals. Sheets of gold may be beaten out so thin that they are almost transparent. It is estimated that 300,000 such sheets laid one upon the other would be required to make a layer an inch in thickness.

161. Ductility. *Ductility* is that property by virtue of which a substance may be drawn out into threads. Glass at ordinary temperatures is very brittle, but when heated it becomes very ductile. If a small glass tube be placed in a flame for a few moments it becomes soft and pliable. It can then be drawn out into very fine threads which are flexible and highly elastic. "Glass wool" which is sometimes used for laboratory purposes is made by forcing a stream of air through molten glass, which by this means is blown out into exceedingly fine fibers, somewhat resembling wool in color and elastic properties.

Most metals are ductile and hence are capable of being drawn out into wire. Iron and copper wire furnish good examples of the ductile properties of these metals. Platinum is one of the most ductile metals known. It can be drawn into wire so fine as to be almost invisible.

When metals are drawn into wire their tenacity is in general increased. If a rod of iron, for example, be drawn into wire and the wire be twisted into a rope or cable, it has been found that the cable thus formed will support a greater weight than would a given length of the original rod. The cable also possesses the advantage of flexibility.

162. Crystallization. When the molecules of a substance are arranged in a definite order, the substance is said to be in a crystalline condition. When the molecules have no definite arrangement the structure is said to be amorphous. Ice is a good example of a crystalline substance. The formation of frost on the window pane in winter gives some idea of the great variety of crystalline forms which water assumes on freezing.

Blackboard crayon is an example of an amorphous substance. Most forms of glass, such as window glass, tubing, test tubes, beakers, etc., are amorphous.

Carbon occurs in nature in three forms, two of which are crystalline, namely graphite and diamond, and the third amorphous — coal, charcoal and lampblack. Water in its



FIG. 193.—Crystals of hoarfrost on a wire fence

various states—liquid, mist, vapor—crystallizes into an almost infinite number of forms, as seen in the snowflake, the beautiful feathery crystalline traceries on the window-pane, and frozen hoarfrost, Fig. 193.

Many crystalline substances assume definite geometrical forms, as illustrated by crystals of quartz, Fig. 194 *I*, and gypsum, 194 *II*. The nature of a substance is often determined by the crystalline form which it assumes.

In general when substances crystallize they expand. Water, for example, in freezing exerts an enormous expansive force, as is seen in the bursting of water pipes in winter, the upheaval of cement walks, and the disintegration of rocks. Indeed, the major portion of the soil is formed by the crumbling of the rocky material of the earth's crust, due, in a large part to the expansive power of freezing water.

TENSILE STRENGTH AND ELASTICITY

163. Tensile or Breaking Strength of a Substance. In the construction of machinery, of bridges, and of modern buildings, especially of the skyscraper type, it is of extreme im-

portance that we have an accurate knowledge of two things: First, the "load" which is to be placed upon each beam and girder, and second the breaking or tensile strength of the material entering into the structure. In the case of a building, the load includes the weight of the various parts of the structure and its contents. In addition to the "dead" weight, however, other force factors have to be taken into account, as, for example, wind pressure, and in the case of auditoriums and grandstands the application of forces such as occur when large bodies of people suddenly arise from a sitting position. An investigation of some of the stresses produced by move-



I *II*
FIG. 194.—Crystals of quartz (*I*) and gypsum (*II*)

ments of "live loads," carried out some time ago at Johns Hopkins University, Baltimore, revealed most interesting and important facts for engineers and builders. It was found for example that the act of suddenly standing up from a crouching position on a platform scale, Fig. 195, added over 60 per cent to the force due to the man's weight.

Tensile strength or tenacity is that property of a substance by virtue of which it resists being torn apart. A strip of paper is quite easily pulled apart; its tenacity is relatively small. Iron, on the other hand, is not easily torn apart; its tenacity is great. The relative breaking or tensile strength of various metals is about as follows: lead, 1; silver, 14; copper, 20; iron, 30.

The tensile strength of a substance is affected by its composition, and by the treatment to which it has been subjected.

For example, a slight change in the carbon content of steel may affect its tensile strength enormously. Thus a specimen of mild steel containing 0.2 per cent of carbon has a tensile



FIG. 195.—The act of suddenly rising from a crouching position may add over 60 per cent to one's "dead" weight

strength of 70,000 pounds per square inch, while another specimen having a carbon content of 0.8 per cent has a tensile strength of 140,000 pounds per square inch. The tensile strength is also affected by annealing, by tempering, and by drawing into fine wire.

Some specially prepared steels, such as those which are used in the manufacture of piano wires, have a tensile strength as high as 300,000 pounds per square inch.

164. Elasticity. *Elasticity* is that property by virtue of which a body tends to recover its shape or volume after being distorted. A body is distorted when it is bent, stretched, twisted, or compressed.

If a meter stick, for instance, be bent in the middle, the molecules on one side may be conceived of as being crowded together, and on the other side as pulled apart. The molecular forces on the one side are repellant and on the other side attractive. The action of these forces tending to straighten the stick gives rise to the property of elasticity. If a rubber ball be dropped upon the floor it will rebound, due to its elasticity. When the ball strikes the floor it flattens somewhat, the molecules in the ball next to the floor being crowded together. The molecular forces within the ball cause it to recover its shape, and in this recovery occurs the rebound. If a steel ball be dropped upon a marble slab, or other hard substance, upon which there is

a coating of fine dust, it will flatten somewhat before rebounding, as shown by the imprint in the dust, in exactly the same manner as did the rubber ball, only to a much less degree.

165. Hooke's Law. Let a rod be clamped at one end and a force applied to the other so that the rod is bent (distorted) through a given distance. Now let the bending force be removed, and if the rod move back exactly to its original position, we say that it was bent within its elastic limits. If, however, the rod be bent so far that it does not go back to its former position, we say that it was bent beyond its elastic limits. When a body recovers completely its original form or volume after being distorted, it is perfectly elastic within the limits of its distortion.

The relation between the force applied to an elastic body and the resulting distortion of the body is expressed by Hooke's Law, which may be stated thus: *Within the elastic limits of a substance the distortion produced is proportional to the force applied.*

Hooke's law may be illustrated by the apparatus of Fig. 196, *I* and *II*. Consider first *I*. A rod is clamped at one end, the other being free to bend. The zero position of the

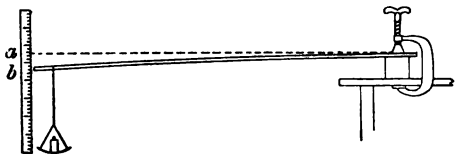
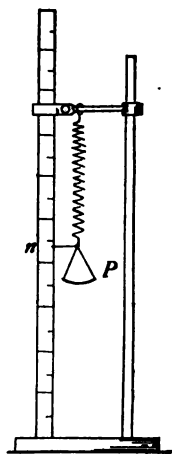
*I**II*

FIG. 196.—Apparatus for illustrating Hooke's Law

free end is noted, and then a given weight is added. Suppose that this causes a bending of 1 inch. Now if twice as much weight be added, the rod will bend 2 inches, and so on until the elastic limit is reached. According to Hooke's law then, if a given force will bend, twist, or stretch a body through

unit distortion, the application of twice as much force will produce twice the bending, twisting, or stretching; three times the force, three times the distortion, and so on until the limit of elasticity is reached. The apparatus shown in Fig. 196 II, enables one to verify Hooke's law by stretching.

EXERCISES. 2. If a force of 10 lb. stretch a given wire $1/100$ in. what will be the stretch due to a force of 50 lb.?

3. Assuming that Hooke's law holds, what force will be required to stretch the wire $1/10$ in.?

166. The Relation of the Stretch of a Rod or Wire to the

Force Applied. Let two wires of the same length and cross section, one of steel and the other of copper, be suspended side by side, Fig. 197, and weights added until each wire is stretched through a given distance, 0.3 cm say. It will be found that it requires nearly twice as much force to stretch the steel as to stretch the copper. We say, therefore, that the elastic constant, or coefficient of elasticity of steel is about twice that of copper. *Coefficient of elasticity* may be defined as the ratio of the stretching force per unit area to the elongation per unit length.

The coefficients of elasticity have been experimentally determined for practically all building materials, and these constants are of great value to engineers and builders, as they are enabled beforehand to calculate the length that a given beam or rod will bend or stretch when a given load is applied.

167. Some Physical Properties of Iron. Since iron in some form enters into nearly every important building operation, its physical and chemical properties have been very carefully studied. This is particularly true with reference to its resistance to forces tending to stretch, bend, or twist it. There are a number of different kinds of iron, the most common being cast

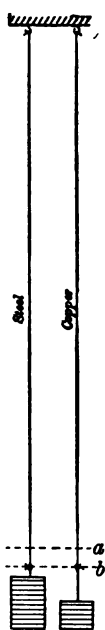


FIG. 197
Comparison
of elastic
coefficients

iron, wrought iron, and steel. The physical properties of iron, such as tenacity, brittleness and elasticity, are due mainly to the presence of other substances such as carbon, sulphur, and phosphorus.

Cast iron is a brittle, highly crystalline form, and its physical properties are due probably to the relatively high percentage of carbon which it contains, 2 to 3 per cent. Cast iron expands on solidifying, and to this property is due its use in molding. The hot metal in a liquid condition is poured into molds, and on solidifying it crystallizes and expands, filling exactly the outline of the mold, after which it contracts somewhat. Many familiar articles of household use are made of cast iron, such as kitchen stoves, pots, kettles, etc.

Wrought iron is produced by burning most of the carbon out of cast iron by exposing the molten metal to a stream of air and by working the iron while hot. Wrought iron is softer and very much tougher than cast iron and, unlike the latter, can be welded. The iron used by the blacksmith in most of his work is wrought iron. One of the most familiar examples of wrought iron is the common nail.

Steel contains less carbon than cast iron and more than wrought iron. It is highly elastic, very tenacious, and is capable of being tempered, that is, hardened. Nearly all edge tools are made of steel. The rails of car tracks are in general made of this material, as are also the beams and girders of our modern iron buildings.

168. Stiffness and Strength of Beams. In the use of rods and beams in building operations it is often desirable to secure the greatest strength and stiffness with the least weight of material. To accomplish this, beams are not made of compact form, but rather of a cross section like the patterns shown in Fig. 198, since a given amount of material is more effective in resisting a bend or a twist when placed some distance from its center of cross sec-



FIG. 198
Stiffness and
strength of beams

tion. For this reason the steel "I" beam is commonly used in the construction of buildings. When it is necessary to combine lightness with great stiffness, the tubular form is almost always used, as in the frame of the flying machine and the bicycle. In nature we find many examples of this combination of strength and lightness, as in the case of the hollow stalks of grain, the bones of the body, and the quills of birds.

It must not be understood, however, that a hollow beam is stronger than a solid one of the same dimensions. *A hollow beam is stronger than a solid one of the same weight, but not of the same dimensions.* If the saving of weight and material were no object, beams would always be made solid.

SURFACE TENSION AND CAPILLARY ACTION

169. The Surface of a Liquid. One of the most striking illustrations of the action of molecular forces is found in the

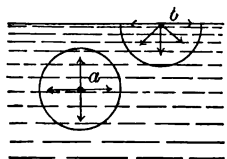


FIG. 199

study of the surface of a liquid. Consider the molecules of a liquid, as shown in Fig. 199. Molecule *a*, for example, is attracted equally in all directions within the range of the molecular forces, hence is in equilibrium. A molecule in the surface layer *b*, for instance, is not

attracted equally in all directions, the force downward being greater than the force upward, because the molecules of water attract water with a greater force than do molecules of air. Hence it follows that the molecules of the surface layer are drawn downward, and are therefore a little closer to their neighbors than are the molecules of any other part of the liquid. This gives rise to a tension in and parallel to the surface of the liquid, called *surface tension*. *The surface of every liquid is under a state of tension and acts exactly as if it were a stretched membrane.*

170. Illustrations of Surface Tension. (a) If a wire ring, having a loop of thread tied to it, be dipped into a soap solution and then withdrawn so that a film is formed across it, the loop of thread will lie on the face of the film. If now the film be punctured inside the loop, the thread will spring out into a circle, the tension of the film pulling the loop outward equally in all directions, Fig. 200.

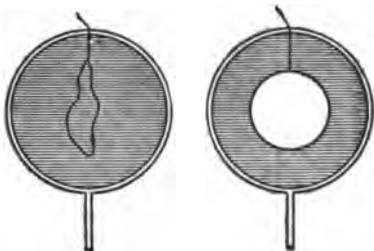


FIG. 200.—Surface tension pulls the loop out into a circle

(b) If a film be formed across the mouth of a funnel by dipping it into a soap solution, it will be observed that the film creeps down the funnel toward the small end, due to its tendency (surface tension) to contract. The same phenomenon may be seen in the case of the contraction of a soap bubble blown from a pipe, Fig. 201.

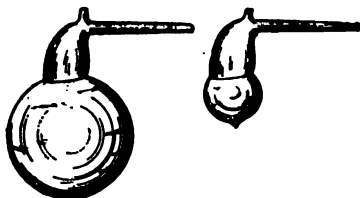


FIG. 201.—Surface tension causes the soap bubble to contract

(c) Let a film of water be spread out over a clean glass plate. Now put a drop of alcohol on the water and the film will be torn asunder at the point of contact, due to the fact that the surface tension of water is greater than that of alcohol.

(d) If by means of a wire holder a needle be carefully placed upon water, the membrane-like surface will cause it to float. Certain insects may be seen in the summer time running about on the surface of still water. They are supported by the tough surface layer of the liquid.

171. The Spherical Form of a Drop of Liquid. When a drop of liquid is free to follow its tendencies, unaffected by forces without, surface tension draws it into the form having

the least volume, that is, a sphere. Rain drops tend to become spherical because of surface tension; the drop of dew on the petal of a rose is spherical, or nearly so, because of the same force. Drops of molten lead falling from a great height, as from the top of a shot tower, take on a spherical form as they fall due to surface tension, and cooling as they descend, retain their shape when they plunge into water at the bottom of the tower. Small globules of mercury are very nearly spherical despite the great weight of the metal, because of the tendency of the surface layer to force the liquid into the smallest possible volume.

172. Oil on Water. If a drop of light oil be placed on water it quickly spreads out over the surface. This is due to the fact that the surface tension of water is greater than that of the oil, and hence the latter is drawn out into a thin film.

The effect of oil in stilling a rough sea has been known from the earliest times. This method of calming a heavy sea about a ship is now frequently practiced. The oil makes the water calm only in the sense that it reduces the short choppy waves to a more or less smooth swell. The action of oil, therefore, in "stilling troubled waters" is not altogether a poetic fancy.

Let us assume that a wind is blowing, tending to heap the water into waves. Suppose that the wind strike a surface area A which is covered with oil. The force of the wind strips the oil off this area and heaps it up in an area B beyond. The surface tension of A is now greater than at B , and, therefore, the pull back is greater than the pull forward. Thus the motion of the wave AB will be retarded to a greater degree than if it were free from the film of oil. The oil thus seems to check the relative motion of the parts of the surface, and so prevents a heaping up of the water. It is the heaps of water which under wind pressure develop into the waves which are characteristic of a high sea.

173. Capillary Action. A capillary tube is one having a very fine, hairlike bore. If one end of a capillary tube of glass

be thrust into water, the liquid rises, Fig. 202 *I*; when thrust into mercury, the liquid falls, Fig. 202 *II*. The elevation or depression of the liquid depends on the nature of the curved surface of the liquid within the tube. When the surface is curved downward, that is, depressed in the middle as in water, the liquid rises; when curved upward, as in mercury, it falls. The surface of all liquids form a more or less acute angle with solids, hence there is in general always some capillary action. The surface of water forms a very sharp angle with glass; alcohol very nearly a right angle with silver. The capillary action in the case of

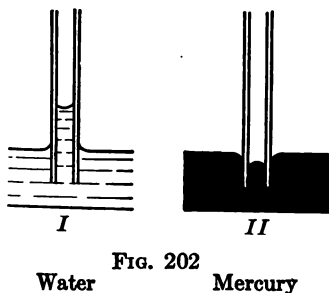
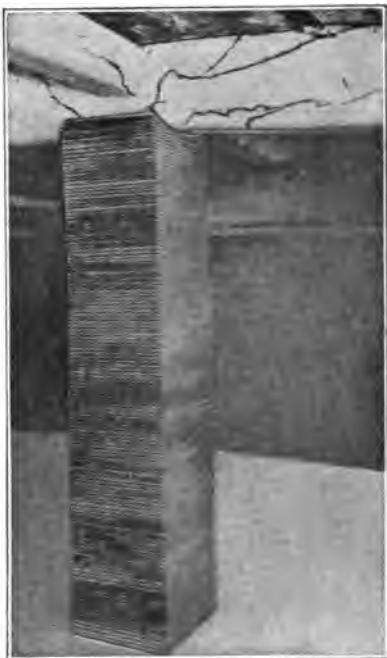


FIG. 202

FIG. 203.—Heavy concrete beam cracked by the swelling of a pile of water-soaked boards



water against glass is therefore very pronounced; that between alcohol and silver very slight.

The rise of oil in the wick of a lamp, the passage of ink into a blotter, and the flow of ink in the slit of a pen are all familiar illustrations of capillary action. Capillary action accounts in the main for the passage of water into a rope, or between

the fibers of wood, thus causing the wetted rope or wood to swell. A remarkable example of the force exerted by the swelling of lumber when wet is that illustrated in Fig. 203.

The factors which influence capillary action are: (a) The surface tension of the liquid. Surface tension is the force which causes the ascension or depression of the liquid in the tube, the ascension or depression being directly proportional to the surface tension.

(b) The curvature of the liquid in the tube. If the liquid wets the tube, and as a result the surface is concave (as in the case of water against glass) the liquid rises; if, on the other hand, the liquid does not wet the tube, and the surface is convex (mercury against glass) the liquid descends.

(c) The ascension or depression of the liquid is inversely proportional to the diameter of the tube; that is, the smaller the tube the greater the ascension or depression.

(d) The elevation or depression of the liquid decreases as the temperature increases.

TABLE XIII

SURFACE TENSION IN DYNES PER CM.

Water.....	75
Mercury.....	535
Olive Oil.....	37
Turpentine.....	29
Alcohol.....	26

174. Capillary Action in Soils. The distribution of moisture in the soil depends to a large extent upon capillary action. When the soil is compact, the minute spaces between the soil particles act as capillary tubes, thus aiding the water to rise to the surface. As the water evaporates from the surface, more of it rises by capillary action from the damper soil below, until the ground is thoroughly dried out.

If, on the other hand, the top soil is kept loose by cultivation the spaces between the particles are too large for much capillary action to take place, and thus the moisture in the

soil is conserved. In the semi-arid regions of the West "dry farming" is successfully practiced. This consists in keeping



I



II

FIG. 204.—Illustration of capillary action as applied to soil cultivation

the surface covered with a "dust mulch" produced by frequent cultivation. In this way the moisture is kept below the surface, where it can be utilized during the hot dry summer by the roots of growing plants.

The principle by which cultivation of the soil conserves moisture may be illustrated by taking a lump of sugar and dipping one end of it into coffee. The coffee will rise rapidly through the whole lump, Fig. 204 *I*. If now a little loose sugar be sprinkled over the top of the lump, with a spoon, Fig. 204 *II*, it will be found that the coffee when it rises to this point, will take considerable



FIG. 205.—Soil in footprint is dry and hard due to capillary action

time to pass through this loose sugar. This is the principle of the mulch in saving moisture. In Fig. 205 there is shown the impression of a shoe in a cultivated field. Where the earth is packed under the foot capillary action has taken place and the soil is dry and hard; around the footprint the soil is loose and underneath it is moist.

DIFFUSION AND ABSORPTION

175. Diffusion of Gases and Liquids. One of the best evidences of molecular motion is that furnished by the diffusion of two fluids. If a tube containing hydrogen (atomic weight 1) be inverted over a similar tube containing oxygen (atomic weight 16) the two gases will mix, notwithstanding the fact that the lower gas (oxygen) is 16 times as heavy as the upper. The diffusion of one gas into another is due to the motion of the molecules of the gases. Hydrogen and oxygen form an explosive mixture. The fact that diffusion actually takes place in the case of hydrogen and oxygen may be demonstrated by applying a lighted match to either tube after the two gases have been in contact for some time. A slight explosion occurs, thus showing that the gases have mixed.

It can be shown, also, that a heavy liquid will diffuse upward into a lighter one. In a large test tube place a solution of litmus. By means of a thistle tube pour some sulphuric acid into the tube below the litmus solution. The sulphuric acid is considerably heavier than the litmus solution, and the line of demarcation between the two is sharply defined. In a few hours this line of separation will have moved upward, showing that the heavy acid is diffusing up into the lighter liquid above it.

Carbon dioxide (CO_2) is about 1.5 times as heavy as air, yet it mixes readily with the air, due to the tendency of fluids to diffuse.

176. Diffusion of Gases through Solids. Lower a large glass jar filled with some light gas, such as hydrogen or illuminating gas, over a porous cup, to the lower end of which is sealed a bent glass tube containing colored liquid, Fig. 206. The light gas in the jar diffuses readily through the walls of the porous cup, thus giving rise to a pressure which is manifested by the rise of the colored liquid in the bent tube. If now the glass jar be removed from over the porous cup, the light gas which has diffused into the cup will now diffuse outward, creating thus a partial vacuum within the cup. This is shown by the fact that the colored liquid in the bent tube rises toward the cup, above its position of equilibrium *ab*.

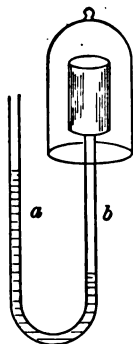


FIG. 206

The lighter a gas the more readily will it diffuse through porous solids. The rate of diffusion of two gases through a porous partition is inversely proportional to the square root of their densities. For example, the weight of hydrogen is to that of oxygen as the ratio of 1 : 16. Hence the rate of diffusion of hydrogen is to the rate of diffusion of oxygen as $\sqrt{16} : \sqrt{1} = 4 : 1$. That is, hydrogen will diffuse 4 times as fast as oxygen.

Some gases will diffuse through metals under certain conditions. Carbon monoxide, for example, will diffuse readily through cast iron when the latter is red-hot; hydrogen, also, will diffuse through red-hot platinum.

177. Absorption. Porous solids absorb liquids and gases. The absorption of a liquid by a solid may be illustrated by means of a device shown in Fig. 207. The apparatus consists of a porous cup into the end of which is fitted, by means of a rubber stopper, a bent glass tube containing a little mercury. If the cup be placed in a beaker of water the mercury will rise



FIG. 207

in the outer arm of the tube, thus showing an increased pressure inside the cup due to the absorption of water by its walls.

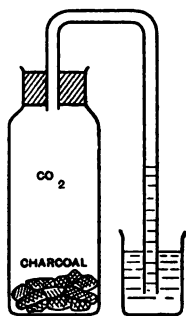


FIG. 208
Absorption of
carbon dioxide
by charcoal

Some solids have the power to absorb gases to a remarkable degree. This is especially true of freshly burned charcoal, as may be demonstrated by means of an apparatus as shown in Fig. 208. Some freshly burned charcoal, cooled to room temperature, is put into a wide-mouthed bottle filled with carbon dioxide, CO_2 . The bottle is then closed with a rubber stopper into which is fitted a bent glass tube as shown. The lower end of the tube dips into a beaker of colored liquid. The charcoal quickly absorbs a considerable portion

of the carbon dioxide, thus creating a partial vacuum which is manifested by a rapid rise of the colored liquid in the tube.

178. Osmosis. If into a thistle tube, over the end of which there has been fastened a membrane, there be put a solution of sugar and water and the tube immersed in a beaker of water, Fig. 209, it will be observed that after a time the liquid in the tube will begin to rise. The water in the beaker passes through the membrane more readily than the sugar solution passes out. The rise of the liquid in the tube is due to a pressure called *osmotic pressure*. The process by which liquids pass through membranes is called *osmosis*. A complete and satisfactory explanation of the causes of osmotic action has not yet been found. Suffice it to say that osmosis is due to molecular forces and depends upon the character of the liquids separated by the membrane, and also upon the nature of the membrane itself.

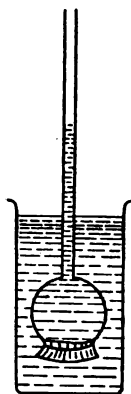


FIG. 209
Osmotic
pressure

The principle of osmosis plays a most important part in the life of plants and animals. Soluble food ingredients in the soil pass through the thin walls of the rootlets of plants by osmosis. So, too, soluble food substances in the human body enter and leave the circulation by the same means. Oxygen of the air also enters the blood through the thin-walled cells of the lungs by osmosis; likewise the carbon dioxide of the blood is given off.

179. Dialysis. Substances which do not crystallize, such as starch and gelatine, and which do not pass through membranes readily, are called *colloids*; substances which crystallize, as sugars and salts, and which pass through membranes readily when in solution, are called *crystalloids*. The separation of a crystalloid from a colloid is called *dialysis*. Arsenic, for example, if mixed with ordinary articles of food may be separated from the starchy constituents of a solution by dialysis. The mixture is put into a vessel having a membranous bottom, and the whole is suspended in water. The arsenic readily passes through the membrane into the water, where it may be easily detected by chemical analysis. In this way the presence of crystalloid poisons is sometimes detected in food.

REVIEW EXERCISES

1. Define: (a) molecule, atom. (b) How many atoms are there in a molecule of water? in a molecule of sodium chloride?
2. Define: cohesion, adhesion, ductility, malleability.
3. Name three examples of (a) crystalline substances; (b) amorphous substances.
4. Name some of the factors that determine the tensile strength of a substance. How does the carbon content of steel affect its tenacity?
5. (a) Define elasticity. (b) What is meant by the elastic limit of a substance?
6. State Hooke's law. Explain how it may be verified experimentally.
7. Physical properties of iron: (a) cast iron; (b) wrought iron; (c) steel.

8. Explain how beams may be made stiff and strong and at the same time be relatively light in weight.
9. Explain by means of a sketch surface tension in liquids.
10. Give illustrations of surface tension.
11. Explain why liquid drops tend to become spherical in form.
12. What are the factors which affect capillary action? What is the force which pulls the liquid up or down in the capillary tube?
13. How is the elevation or depression of a liquid in a capillary tube affected by (a) the size of the bore? (b) the temperature?
14. Explain why cultivating the soil conserves the moisture within it.
15. Define: osmosis, crystalloid, colloid, dialysis.

CHAPTER VI

HEAT

TEMPERATURE

180. Nature of Heat. Heat was formerly believed to be a subtle fluid called "caloric," which on entering a body produced the phenomena of hotness, burning, and so forth. About the end of the eighteenth century, however, Count Rumford demonstrated that the caloric theory (fluid theory) of heat is untenable. During the supervision of the boring of some brass cannon, he noted that there was some relation between the work done by the horse driving the machinery and the heat developed by the boring tool. At this time it was supposed that heat was a fluid. Rumford decided that there must be a definite relation between the motion of the particles of brass and the heat generated. He went so far as to measure the quantity of heat given off in the boring of a cannon, and in this experiment he came very near to discovering the mechanical equivalent of heat.

Count Rumford (Benjamin Thompson) was one of the most interesting characters of his day. He was born in Massachusetts in 1753. He went to England during the Revolutionary period, and later went to Germany where he settled at Munich, in the employ of the elector of Bavaria, with whom he acquired great influence. On the occasion of receiving the title of Count, in 1790, he chose the name Rumford after the village in New Hampshire where he had resided prior to leaving for England.

In 1799 Sir Humphrey Davy gave the death blow to the caloric theory by showing that two pieces of ice can be liquefied at the freezing point by rubbing them together, thus proving that heat is not a fluid, but a form of energy. The

experiments of Rumford and Davy laid the foundation for the modern kinetic theory of heat, which assumes that heat is related to molecular motion. According to this theory, if the molecular motion of a body be increased the body becomes hotter; if the motion be decreased it becomes cooler. If a piece of metal be struck with a hammer, both the metal and the hammer become heated, because of the increased molecular motion due to the blow. Also if a piece of iron be thrust into the fire it becomes heated, because of the increased molecular motion imparted by the flame.

Heat may be defined as a form of energy due to the molecular motion of a body.

The principal sources of heat are: (a) the heavenly bodies, such as the sun, the stars, and so forth; (b) the interior of the earth; (c) chemical action, as in the combustion of wood or coal; (d) electrical energy, as in the heating of the filament of an incandescent lamp; (e) mechanical sources, such as friction, impact, and so forth.

181. Temperature. The *temperature* of a body is that which determines its degree of hotness or coldness. We speak of boiling water as having a high temperature; of ice cold water as having a low temperature. The temperature of a body is determined by the average kinetic energy of its molecules; the greater the molecular motion the higher the temperature.

We depend in a great many cases upon our sensations of hot and cold to determine the relative temperature of bodies. In this manner we may determine that a steam pipe is hot and that ice is cold. This primitive method of determining temperature, however, is not reliable, as may be illustrated by a simple experiment. Take three basins of water, one hot, one cold, and one tepid. Place one hand in the hot water and the other in the cold and hold them there for a moment. Now place both hands in the tepid water. The hand that was in the hot water will feel cool and the hand that was in

the cold water will feel warm. Thus the sensations of hot and cold may give us unreliable information as to the actual temperature of the water in the third basin. It is therefore necessary to have some more satisfactory means of measuring temperature, and for this purpose we use a thermometer.

182. The Mercury Thermometer. A *thermometer* is an instrument for measuring temperature. The measurement of temperature by means of the mercury thermometer depends upon the principle that "heat expands, and cold contracts."

The expansion of a substance due to heat may be illustrated by means of a piece of apparatus as shown in Fig. 210. A small flask having a glass tube thrust into the rubber stopper is filled with colored water. If now the bulb be put into a beaker of hot water two things may be observed: (a) First, the liquid in the tube falls slightly and then (b) it rises rapidly to a given height. The liquid falls at first because of the initial expansion of the glass bulb; the heat, however, soon affects the liquid, which, expanding more rapidly than the glass, rises in the tube.

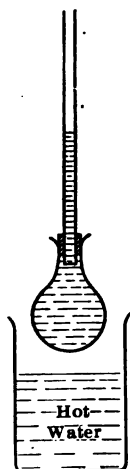


FIG. 210
A water thermometer

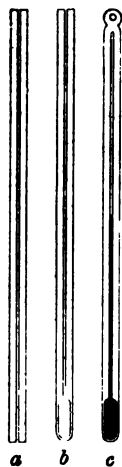


FIG. 211
Showing how a thermometer is made

The mercury thermometer consists of a glass tube containing mercury as the expanding substance. The thermometer is constructed and filled as follows: On the end of a glass tube having a capillary bore *a*, Fig. 211, there is blown a thin-walled bulb *b*. This bulb and a short portion of the capillary are filled with mercury by expelling the air from the bulb by heating, and then thrusting the open end of the tube into the mercury, which rises in the tube as the air in the bulb cools and contracts. The instrument is now in-

verted and heated until the mercury expands sufficiently to fill the entire bore, at which time the tube is sealed off at the top, as shown in *c*, thus leaving it air tight. When the thermometer cools the mercury contracts into the lower part, leaving the major portion of the capillary free.

183. The Fixed Points on a Thermometer. In order to establish a thermometer scale it is necessary to determine two fixed points. These points are the freezing and boiling points of water under a pressure of one atmosphere. The *freezing point* on the scale is determined by placing the bulb and part of the stem in finely crushed ice, Fig. 212 *I*. The mercury in the bulb contracts, and hence the thread of mercury in the capillary falls. The point at which it comes to rest is marked. This is called the freezing point; it is the temperature at which water freezes or ice melts, the two points being practically the same.

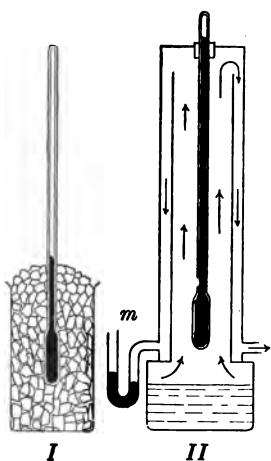


FIG. 212.—Freezing and boiling points

The *boiling point* is determined by suspending the thermometer in steam arising from water boiling under a pressure of one atmosphere. The apparatus used in determining the boiling point is shown in Fig. 212 *II*. The required pressure of one atmosphere is determined by means of the manometer gauge *m*. As the thermometer becomes heated by the steam, the mercury rises to a certain point, where it remains stationary. A mark is made on the scale to indicate this point, which is called the boiling point.

184. The Fahrenheit Scale. This scale was first used by Fahrenheit, a German scientist. The interval between the freezing point and the boiling point is divided into 180 degrees, usually written 180° . The zero of the scale is set at 32° below the

freezing point, thus making the interval from the zero of the scale to the boiling point 212° . There is no advantage, as we now know, in having the zero at 32° below the freezing point. The Fahrenheit scale is inconvenient and remains in use largely through custom.

185. The Centigrade Scale. The Centigrade scale was first suggested by Celsius, a Swedish astronomer and physicist. The interval between the freezing point and the boiling point is divided, as the word centigrade suggests, into one hundred grades or degrees. The zero of this scale is at the freezing point of water. The Centigrade thermometer is used in all scientific measurements of temperature and is, on account of the simplicity and convenience of the scale, coming more and more into common use.

186. Comparison of Centigrade and Fahrenheit Scales. In Fig. 213 the two scales are drawn side by side for comparison. Since the interval between the freezing point and the boiling point is the same for both scales, differing only in the number of units marked on each, and since 100 C units are equal in length to 180 F units, it follows that for a given length of scale

$$\text{No. } C \text{ units: No. } F \text{ units} = 100 : 180 = 5 : 9$$

Now, bearing in mind that to change from one scale to the other it is necessary to reckon from some fixed point such as the freezing point and to do this we must always take into account the 32 units between zero and the freezing point of the Fahrenheit scale, to change temperature readings from one scale to the other we may use the equations

$$C = \frac{5}{9} (F - 32), \text{ and}$$

$$F = \left(\frac{9}{5} C\right) + 32$$

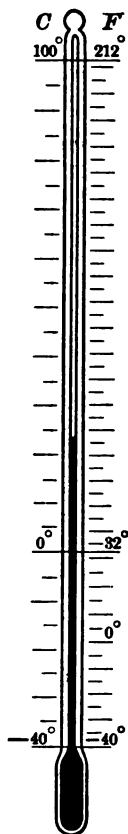


FIG. 213
Centigrade
and Fahrenheit
scales

Examples. 1. A reading of $+113^{\circ}\text{F}$ is equivalent to what reading on the C scale? *Solution:* $C = \frac{5}{9} (+113 - 32) = \frac{5}{9} (+81) = +45^{\circ}\text{C}$.

2. A reading of $+23^{\circ}\text{F}$ is equivalent to what reading on the C scale? *Solution:* $C = \frac{5}{9} (+23 - 32) = -5^{\circ}\text{C}$.

3. A reading of -13°F is equivalent to what reading on the C scale? *Solution:* $C = \frac{5}{9} (-13 - 32) = \frac{5}{9} (-45) = -25^{\circ}\text{C}$.

4. A reading of 20°C is equivalent to what reading on the F scale? *Solution:* $F = \frac{9}{5} (+20) + 32 = +36 + 32 = +68^{\circ}\text{F}$.

5. A reading of -20°C is equivalent to what reading on the F scale? *Solution:* $F = \frac{9}{5} (-20) + 32 = -36 + 32 = -4^{\circ}\text{F}$.

EXERCISES. 1. Give for the following C readings their equivalents on the F scale: (a) $+10^{\circ}\text{C}$; (b) -10°C ; (c) $+30^{\circ}\text{C}$; (d) -30°C ; (e) -40°C .

2. Give for the following F readings their equivalents on the C scale: (a) $+32^{\circ}\text{F}$; (b) $+77^{\circ}\text{F}$; (c) $+5^{\circ}\text{F}$; (d) -4°F ; (e) -40°F .



FIG. 214
Clinical
thermometer

187. Limitations of the Mercury Thermometer. The limitations of a thermometric substance are, in general, fixed by its freezing point and its boiling point. Mercury freezes at -39°C and boils at $+357^{\circ}\text{C}$, under a pressure of one atmosphere. It is possible to raise the boiling point of mercury in a mercury-in-glass thermometer to $+500^{\circ}\text{C}$, by increasing the pressure of the gas enclosed within the instrument.

For measuring temperatures below -39°C alcohol is often used as the thermometric substance. This liquid is usually colored red or blue to render it visible against the glass. The freezing point of alcohol is -130°C ; its boiling point $+78^{\circ}\text{C}$.

188. The Clinical Thermometer. This instrument is used by physicians and nurses in taking the temperature of the human body. It is a mercury-in-glass thermometer, Fig. 214, and is characterized by having a narrow constriction *c* in the capillary. When the thermometer cools the mercury thread breaks at this point, leaving the column of mercury in the tube as it was at the highest temperature while in contact with the body. Thus the reading may be made some time after the temperature is taken. Before this thermometer can be used again, the mercury in the stem must be shaken down into the bulb by giving the instrument a jerking motion.

The normal temperature of the human body is 98.5°F .

MEASUREMENT OF HEAT

189. Distinction between Temperature and Quantity of Heat. It is important to note that there is a distinction between the temperature of a body and the quantity of heat which it contains. For example, a tin cup of boiling water has a temperature very much higher than that of the water in a lake under ordinary summer conditions, yet the quantity of heat in the water of the lake is many times greater than that of the water in the cup. The temperature of a body depends on the average kinetic energy of its molecules; the quantity of heat in the body depends therefore not only upon its temperature, but also upon its mass.

190. Unit Quantity of Heat. There are two units employed in the measurement of heat: (a) the calorie, based on the gram mass and the Centigrade scale, and (b) the British thermal unit (B. t. u.), based on the pound mass and the Fahrenheit scale.

A *calorie* is the quantity of heat required to raise the temperature of one gram of water one degree Centigrade. The quantity of heat, for example, required to raise one liter of water (1000 grams) from 20°C to the boiling point (100°C) is $1000 \times (100 - 20) = 80,000$ calories.

A British thermal unit (B. t. u.) is the quantity of heat required to raise one pound of water one degree Fahrenheit. The number of B. t. u. required to raise one gallon of water (about 8 pounds) from 70° F to the boiling point (212° F) is $8 \times (212 - 70) = 1136$ B. t. u.

191. Specific Heat. All bodies do not have the same capacity for heat. If we take one pound of water and one pound of iron and raise the temperature of each one degree, it will be found that while the water will require one unit of heat, the iron will require only about one-tenth of a unit. The *specific heat* of a substance is numerically equal to the number of units of heat required to raise the temperature of unit mass one degree. The specific heat of water is 1; that is, it requires 1 calorie to raise 1 gram 1° C; or in English units it requires 1 B. t. u. to raise 1 pound 1° F. When we say that a substance, as mercury, for example, has a specific heat of 0.033, we mean that it requires 0.033 of a unit (calories or B. t. u.) to raise the temperature of unit mass (gram or pound) one degree (Centigrade or Fahrenheit).

192. How to Find the Specific Heat of a Body. One of the simplest means of determining the specific heat of a body is known as the method of mixtures. A hot body is brought into contact with a cool body; the hot body loses heat and the cool body gains heat. Suppose that we wish to find the specific heat of lead by the method of mixtures. Suspend a given mass of lead in boiling water until the metal comes to the temperature of the boiling water. The temperature of the water should be determined by means of a thermometer. Have at hand a copper beaker (calorimeter), containing a known mass of water. The mass of the calorimeter must also be known. Determine the temperature of the water in the calorimeter and then quickly transfer the lead from the hot water to the calorimeter. Stir gently with a thermometer until the mixture in the beaker (lead and water) comes to a constant temperature, which should be noted. We now

have the following data: The mass of the lead and its change (fall) in temperature; the mass of the water and its change (rise) in temperature; the mass of the calorimeter and its change (rise) in temperature. From these data we may compute the specific heat of the lead.

The calculation of the specific heat of a body by the method of mixtures is based on the assumption that the heat lost by one body is equal to the heat gained by other bodies; that is, in the particular case under consideration, the heat lost by the lead is equal to the heat gained by the water, plus that gained by the calorimeter. Now the heat lost or gained by a body, measured in calories or B. t. u., is equal to the mass of the body times its change of temperature, times its specific heat; therefore, we may write

heat lost by lead = heat gained by water + heat gained by calorimeter

$$m \times t \times s = m' \times t' \times s' + m'' \times t'' \times s''$$

where m is the mass of the body losing heat, t is its change in temperature, and s its specific heat; m' is the mass of the water, t' its change in temperature, s' its specific heat, which is equal to unity; m'' is the mass of the calorimeter, t'' is its change in temperature (the same as that of the water), and s'' its specific heat.

Example. Suppose that an iron ball of mass 52 grams having a temperature of 100°C is dropped into 200 grams of water at 20°C , contained in a copper calorimeter having a mass of 100 grams. The resulting temperature of the calorimeter and its contents is 22.2°C . The specific heat of copper is 0.09. Find the specific heat of the iron. *Solution:* In making a calculation of this sort we assume that the heat lost by the iron is gained by the water and the calorimeter together; therefore, we may write

$$\begin{aligned} m \times t \times s &= m' \times t' \times s' + m'' \times t'' \times s'' \\ 52 \times 77.8 \times s &= 200 \times 2.2 \times 1 + 100 \times 2.2 \times .09 \\ s &= 0.113 \end{aligned}$$

EXERCISES. 3. A piece of nickel having a mass of 114 grams at 100°C is dropped into 100 grams of water at 10°C . The resulting temperature of the water is 20°C . Find the specific heat of the nickel, neglecting the heat lost to the containing vessel.

4. One kilogram of water and one kilogram of iron, each at a temperature of 100°C , are cooled to 20°C . How much heat in calories is given out by each?

5. A person drinks 300 grams of ice water which comes to the temperature of the body (98.5°F). How many calories of heat are taken up by the water?

TABLE XIV

SPECIFIC HEATS

Air.....	0.237	Iron.....	0.113
Alcohol.....	0.602	Lead.....	0.03
Aluminum.....	0.22	Marble.....	0.21
Brass.....	0.094	Mercury.....	0.033
Copper.....	0.09	Silver.....	0.056
Glycerine.....	0.55	Steam, 100°C , 76 cm.....	0.48
Glass.....	0.2	Water.....	1.00
Ice.....	0.5	Zinc.....	0.094

EFFECTS OF HEAT

193. Introductory. (a) *Sensations of warmth and cold.* The most noteworthy effect of heat is that experienced in the effects produced in our bodies in the sensation of warmth, or in the absence of heat, the sensation of cold. Bodily heat is one of the prime necessities of life. The problem of regulating the natural heat of the body by means of proper clothing and of heating our houses in cold weather is therefore of primary importance. A discussion of combustion, fuels, and methods of heating will be considered under a later topic. (b) *Expansion.* In general heat causes solids, liquids, and gases to expand; cold, on the other hand, causes them to contract. There are some exceptions to this rule as applied to solids and liquids. (See Art. 198.) (c) *Fusion.* Heat causes solids to fuse or melt. And (d) *Vaporization.* Heat causes solids and liquids to vaporize.

194. Expansion of Solids. The expansion of a metal may readily be demonstrated to a class by means of the ball and ring experiment. A brass ball, Fig. 215, when cold will just pass through the ring. Heat the ball for a few moments in a bunsen flame. The ball expands and now will not pass through the ring. In some cases the ball is made of a size so that when cold it is slightly larger than the ring. In this case the ring is heated, allowing the ball to slip through. Telegraph and telephone wires in winter are stretched taut from pole to pole. In summer, when they are exposed to the fierce rays of the sun, they expand and sag until they are much too long. If the wires were stretched taut in the summer, there would not be sufficient leeway for the contraction which accompanies cold weather, and they would snap under the strain.



FIG. 215
Ball and ring
experiment

The snug fit of metal tires and bands is due to the expansion and contraction resulting from heating and cooling. The tire of a wagon wheel is made slightly smaller than the wheel which it is to protect; the tire is then heated until it has expanded sufficiently to slip onto the wheel. As the tire cools it contracts and fits the wheel closely.

In building a railroad, spaces are usually left between consecutive rails in order to allow for expansion during the summer. The unsightly cracks and humps in cement floors are sometimes due to the expansion resulting from heat. Cracking from this cause can usually be avoided by cutting the soft cement into squares, the spaces between giving them opportunity for expansion just as do the spaces between the rails of a railroad.

Heat plays an important part in the splitting of rocks and in the formation of rock soil. Rocks in exposed places are greatly affected by changes of temperature. In regions where the changes of temperature are sudden and frequent,

the rocks are not able to withstand the strain of expansion and contraction, and as a result crack and crumble. In the Sahara Desert such crumbling of the rock into sand has been caused by the change from the intense heat of the day to the cold of night. The heat of the day causes the rocks to expand and the cold of night causes them to contract, and these two forces constantly at work loosen the grains of the rock and force them out of place, thus bringing about disintegration.

The force exerted by metals when expanding or contracting is usually very great. It is estimated that it would require a pressure of nearly 10,000 pounds per square inch to keep mercury from expanding when heated from 0°C to 10°C . Boiler plates are fastened together by heated rivets; when the rivets cool they contract, forming very tight joints.

195. Coefficient of Linear Expansion. The expansion and contraction due to changes of temperature make it necessary for the engineer to take careful account of the expansion factor in the construction of buildings and bridges, the laying of rails on railroad tracks, and in the installation of water and steam pipes. Suppose for example it is desired to put down steel railway rails. One must figure out beforehand just what expansion will take place during the possible extremes of temperature between winter and summer, say from -25°C in winter to $+40^{\circ}\text{C}$ in summer. In order to do this it is necessary to know the rate of expansion of the metal in question. The length rate of expansion is called the coefficient of linear expansion, and may be defined thus: The *coefficient of linear expansion* is the increase in length per degree per unit length, or

$$\text{coefficient of linear expansion} = \frac{l}{t \times L}$$

where l is the change (increase or decrease) in length, t the change in temperature, and L the original length.

Example. A metal rod 1 meter in length expands 2 millimeters when its temperature is increased from 0°C to 120°C .

Find its coefficient of linear expansion. *Solution:* The original length of the rod was 100 cm, and the expansion (increase in length) 0.2 cm. Then for the coefficient of linear expansion we may write: $C. of L. E. = 0.2 / (120 \times 100) = 1/60,000 \text{ cm per degree per unit length} = 0.000017 \text{ cm/degree/cm}$.

EXERCISES. 6. The average range of temperature between winter and summer lies between -25°C and $+40^{\circ} \text{C}$. Give the equivalent readings on the F scale.

7. At a temperature of 0°C an iron pipe is 100 ft. long. Its length increases to 100.12 ft. when heated to 100°C by steam passing through it. Find the coefficient of linear expansion of iron.

8. A brass rod having a coefficient of linear expansion of 0.000018 has a length of 180 cm at 0°C . What will be the length at 100°C ?

9. A steel rail, such as is used on railroad tracks, 30 ft. long and having a coefficient of linear expansion of 0.000012, will increase in length how many inches when the temperature changes from 0°C to 50°C ?

196. Expansion Devices. *The compound bar.* If two strips of different metals, such as brass and iron, be riveted together, Fig. 216, and the compound bar thus formed be heated, it

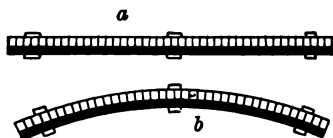


FIG. 216
Compound bar

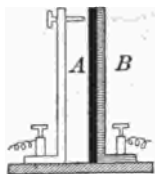


FIG. 217
Alarm thermometer

will bend in the form shown in *b*, due to the fact that the coefficient of expansion of brass is greater than that of iron. Some of the applications of the compound bar principle are illustrated in the following topics.

The alarm thermometer. In Fig. 217 there is shown a device for automatically closing an electric circuit by the bending of the compound bar *B*. If the bar be heated the brass will expand more rapidly than the iron, and thus cause the bar

to bend toward *A* until electric contact is made. Such a device is sometimes used to give alarm in case of fire.

The compound balance wheel. The balance wheel of a watch serves the same purpose as the pendulum of a clock. If the temperature increase, the length of the spokes change thereby, and also the elasticity of the hairspring, causing a change in the period of vibration. To offset this change in the rate of vibration the rim of the wheel is made of a compound bar, the metals of which are arranged in such a way that the outer one expands much more rapidly than the inner one, thus causing the ends *A* and *B*, Fig. 218, to

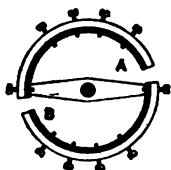


FIG. 218
Compound
balance wheel

bend inward. In this manner the time of vibration of the wheel may be kept practically constant.

Compensating pendulums. We have seen that a change in temperature tends to produce a

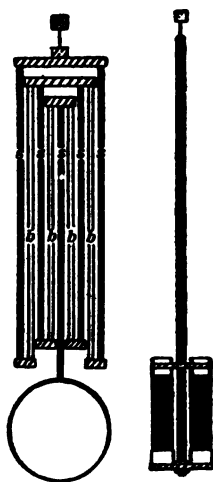


FIG. 219.—Com-
pound pendulums

change in the length of the body. Now any variation in the length of its pendulum will change the rate of a pendulum clock. Several devices, Fig. 219, have therefore been employed to keep the length constant, one such being the so-called gridiron pendulum, in which the lengthening of the rods marked *s*, usually of steel, tends to lower the bob, while the expansion of the rods *b*, usually of brass, raises the bob, and thus the expansion of one set of rods is made to counteract the effect of the other. In the mercury compensating pendulum the lengthening or shortening of the rod is counteracted by a rise or fall of the center of gravity due to the expansion of the mercury in the two glass vessels forming the bob.

TABLE XV

COEFFICIENTS OF LINEAR EXPANSION IN CM PER DEGREE PER CM

Aluminum.....	0.000023	Iron and steel.....	0.000012
Brass.....	0.000018	Lead.....	0.000028
Copper.....	0.000017	Platinum.....	0.000008
Glass.....	0.000008	Silver.....	0.000019
Gold.....	0.000014	Zinc.....	0.000029

197. Coefficient of Cubical Expansion. Thus far we have been talking about linear expansion, that is, expansion of a body in one direction. A body, however, may expand in three directions. Consider for example a cubical piece of metal 4 cm on each edge. It is heated, and as a result expands in three directions, namely, in length, breadth, and thickness. The *coefficient of cubical expansion* for a given substance is equal to three times its linear coefficient of expansion.

The linear coefficient of expansion of glass, as given in Table XV, is 0.000008; its coefficient of cubical expansion is therefore $3 \times 0.000008 = 0.000024$.

EXERCISE. 10. The volume of a cube of brass at 20°C is 1200 cm^3 . Its temperature is raised to 70°C . (a) What is the coefficient of cubical expansion of brass? (b) What is the increase in volume of the brass due to the rise in temperature? (c) What is the volume at 70°C ?

198. Expansion of Liquids. Since liquids conform to the shape of the containing vessel, it follows that in determining their coefficients of cubical expansion, account must be taken of the expansion of the vessel as well as that of the liquid. Like solids, liquids have different coefficients of expansion. For example, the cubical coefficient of expansion of alcohol is 0.00110; that of mercury, 0.00018.

Water is a partial exception to the rule that liquids expand when heated and contract when cooled. If a quantity of water at 0°C be heated, its volume *decreases* until the temperature reaches 4°C , after which the volume *increases* as the tem-

perature rises, at 8°C the volume being about the same as at 0°C . At 4°C , therefore, a given mass of water has its least volume, and hence its greatest density. This fact is of great importance in nature, as is illustrated by the freezing of water in a lake in winter. When the temperature falls the water at the surface reaches its maximum density at 4°C and sinks to the bottom, thus forcing the warm water upward. This goes on until the entire lake reaches a temperature of 4°C , after which the temperature of the water at the surface falls to 0°C and begins to freeze. Since the density of ice is less than that of water at the freezing point, it remains at the surface. The temperature of the water at the bottom of a pond or a lake in winter, is, therefore, 4°C ; indeed, the temperature of the deep water of our great lakes remains at about this point throughout the year.

199. Expansion of Gases. With respect to their expansion, gases differ from solids and liquids in two very important particulars. (a) For a given change of temperature, the rate of expansion of gases is much greater than that of solids or liquids under ordinary conditions; (b) all gases have practically the same coefficient of expansion.

The coefficient of cubical expansion of a gas is $1/273$. That is, if the temperature of a given volume of gas at 0°C and under constant pressure be increased 1°C , it will expand $1/273$ of its volume; if it be heated 10° it will expand $10/273$, and so on, *the expansion in each case being calculated with reference to the volume at 0°C* . If the gas be cooled, the pressure remaining constant, it will contract $1/273$ of its volume at 0°C , per degree.

200. Absolute Temperature. If a gas enclosed within a vessel of constant volume be heated, the pressure which it exerts will increase; if the gas be cooled, the pressure will decrease. The pressure exerted by a given volume of a gas at 0°C is changed $1/273$ per degree of change of temperature. Thus it will be noted that the *pressure coefficient* is the same

as that of the *volume coefficient*, namely, $1/273$. Now, suppose that the temperature of this gas could be reduced 273° below 0°C ; it is evident that its pressure would become zero, which would mean that its molecular motion would also become zero. Since heat is due to molecular motion, it follows that under these conditions there would be no heat. This temperature, 273° below 0°C , is called the *absolute zero*, and a scale based on this zero is called the *absolute scale*.

Readings on the Centigrade scale may be changed to those on the Absolute scale by simply adding 273 to the C values.

Example. Change the following Centigrade readings to Absolute: (a) 0°C ; (b) $+20^{\circ}\text{C}$; (c) -20°C . *Solution:* (a) $0^{\circ}\text{C} = 0 + 273 = 273^{\circ}\text{Abs.}$; (b) $+20^{\circ}\text{C} = 20 + 273 = 293^{\circ}\text{Abs.}$; (c) $-20^{\circ}\text{C} = -20 + 273 = 253^{\circ}\text{Abs.}$

EXERCISES. 11. Give the absolute values for the following Centigrade readings: (a) $+10^{\circ}\text{C}$; (b) -10°C ; (c) boiling point on C scale.

12. Give the equivalent Centigrade values for the following readings on the Absolute scale: (a) 243°Abs. ; (b) 303°Abs. ; (c) 0°Abs.

201. Laws of Charles and Gay-Lussac. The fact that all gases have approximately the same pressure coefficient for constant volume was discovered by Charles, a French physicist; while the corresponding fact that all gases have approximately the same volume coefficient for constant pressure was discovered a few years later by another French scientist, Gay-Lussac. These statements of fact are known as the laws of Charles and Gay-Lussac, respectively.

Charles' law. *When the volume is kept constant, the pressure coefficient of all gases is the same, namely, $1/273$.*

Gay-Lussac's law. *When the pressure is kept constant, the volume coefficient of all gases is the same, $1/273$.*

As a deduction from Gay-Lussac's law, we may make the following statement: *Under constant pressure, the volume of a gas is proportional to its absolute temperature.* This may be written

$$V : V' = T : T'$$

in which V and V' represent the volumes and T and T' the corresponding temperatures on the *Absolute scale*.

Example. A mass of gas having a volume of 100 cm^3 at $+20^\circ \text{C}$ will have what volume at -20°C , the pressure remaining constant? *Solution:* $+20^\circ \text{C} = 293^\circ \text{Abs.}$ and $-20^\circ \text{C} = 253^\circ \text{Abs.}$; hence we may write

$$100 : V' = 293 : 253$$

$$V' = 86.3 \text{ cm}^3$$

EXERCISES. 13. The volume of a given mass of gas under constant pressure at 27°C is 500 cm^3 . What will be its volume at -13°C ?

14. A gas having a volume of 1000 cm^3 at -10°C is heated and expands under constant pressure to 1200 cm^3 . Find the resulting temperature.

MELTING, BOILING, VAPORIZATION

202. Fusion and the Melting Point. *Fusion* or melting is the process by which a solid changes to a liquid upon the application of heat. The melting of ice, sulphur, lead, and tin are all familiar examples of fusion. The temperature at which melting occurs is called the *melting point*.

Many substances like sealing wax, wrought iron, and most kinds of glass have no definite melting point. When heat is applied to such substances, they gradually soften to the point of liquefaction, the change from the solid to the liquid state at no instant being well defined.

Crystalline substances, such as ice, sulphur, cast iron, and most crystalline salts have definite melting points. For example, if a piece of ice at -10°C be heated, the temperature will rise until it reaches 0°C , at which point the ice will melt. The change from the solid to the liquid state, that is, from ice to water, is abrupt, and takes place at 0°C . Likewise, if water be cooled to this temperature, it freezes. The freezing point and the melting point are thus the same, 0°C marking the dividing line between the solid and the liquid state.

The principal facts relating to the fusion or melting of crystalline solids may be summarized as follows:

1. *For crystalline substances, the freezing point and the melting point are the same.*

2. *Every crystalline substance has a definite melting point for a given pressure.*

3. *When a crystalline substance reaches its melting point its temperature remains constant until it is entirely melted.* Thus, when a piece of ice begins to melt, its temperature remains at 0°C until it is all melted, no matter what the temperature of the water in which it may be placed.

203. Heat of Fusion. When a crystalline substance on being heated reaches the melting point, its change from the solid to the liquid state takes place without any rise of temperature. This change, however, requires heat. This heat which is consumed in changing the state of a body without changing its temperature is called the *heat of fusion*, which may be defined as the heat required to change unit mass of a crystalline substance from a solid to a liquid without changing its temperature.

The heat of fusion of ice is 80 calories per gram. That is, 80 calories of heat are required to change 1 gram of ice at 0°C to water at the same temperature.

204. Change of Volume during Fusion. Substances, in general, contract when they solidify and expand when they melt. Thus if molten lead be poured into a bullet mold and there solidify, it will be found that the bullet does not quite fill the mold; the lead contracts on solidifying and expands on melting. Certain highly crystalline substances, on the other hand, such as ice, cast iron, and type metal, expand when they solidify and contract when they melt. Such substances as cast iron and type metal are suitable, therefore, for molding, since they expand on solidifying and thus fill every part of the mold reproducing every detail of the pattern.

205. Water Expands on Freezing. It is estimated that 917 cm^3 of water on freezing will become 1000 cm^3 of ice. A cubic centimeter of ice is therefore lighter than a cubic centi-

meter of water, and hence floats. The pressure exerted by water in freezing is very great, as is often illustrated by the freezing and bursting of water pipes in winter. A cast iron bomb when filled with water and sealed and placed in a freezing mixture will explode with a loud report. This expansion of water in freezing plays an important part in the disintegration of rocks in the formation of soil.

206. Relation of Pressure to Fusion. Pressure applied to a substance which contracts on melting, as ice, for example,

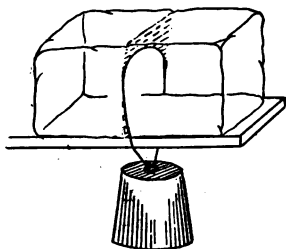


FIG. 220
Melting ice by pressure

lowers the melting point. *Ice may be melted by applying a sufficiently high pressure to it.* Let a fine wire carrying a weight be passed over a small block of ice, as shown in Fig. 220. The ice just below the wire is melted by the pressure, the water thus formed passing above the wire and freezing again on being released. Thus in a short time the wire will cut its way through the ice, leaving

the block as solid as before.

If the temperature be near the freezing point, wet snow may be packed into "ice balls," as nearly every schoolboy knows. Also two pieces of ice may be frozen together under warm water by applying considerable pressure and then releasing them suddenly.

207. Boiling. If heat be applied to a kettle of water the following facts may be observed: (a) First, small bubbles of steam form at the bottom, and as they rise, condense, the walls of the bubbles meeting with a sharp impact and thus giving rise to the phenomenon of "singing." (b) When the temperature of the water rises sufficiently high so that the vapor throughout the liquid has a pressure equal to or greater than that of the atmospheric pressure upon the surface, bubbles form copiously at the heating surface and rise to the top of

the liquid, producing the agitation called boiling. (c) When the temperature of the liquid reaches the boiling point, it (the temperature) remains constant until the water boils away.

Each liquid has a definite boiling point which is constant for constant pressure.

TABLE XVI

MELTING POINTS

Aluminum.....	657° C	Lead.....	327° C
Beeswax.....	62	Mercury.....	-38.8
Butter.....	33	Paraffin.....	45 to 50
Copper.....	1084	Platinum.....	1778
Glass.....	1000 to 1400	Rose's fusible metal...	94
Gold.....	1063	Solder, soft.....	225
Ice.....	0	Sulphur.....	115
Iridium.....	2200	Tin.....	232
Iron.....	1100 to 1200	Tungsten.....	2950

208. Effect of Dissolved Salts on the Boiling Point. Salt dissolved in a liquid raises its boiling point. Most housewives are familiar with the fact that water containing salt boils at a higher temperature than that which is pure. Pure water at a pressure of one atmosphere boils at 100° C. If, however, common table salt (NaCl) be added to the water to the point of saturation, the boiling point may be raised to 109° C.

209. Effect of Pressure on the Boiling Point. The boiling point of a liquid depends upon the pressure exerted upon it. The bubbles that give rise to boiling cannot form in a liquid unless they exert a pressure greater than that of the atmosphere. Therefore, if the pressure upon a liquid be increased, the boiling point is raised. Increasing the pressure raises the boiling point; decreasing the pressure lowers the boiling point.

Put some water at room temperature and atmospheric pressure into a flask, and then connect the flask to an air pump, as shown in Fig. 221. A few strokes of the pump will be sufficient to reduce the pressure so that the water will boil

vigorously. This experiment may be performed in another manner, as follows: Heat the water in a flask until its tem-

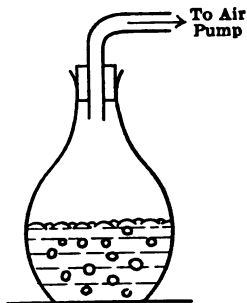


FIG. 221.—Water boiling under reduced pressure

perature is about 70°C , then cork and invert the flask. Now if water be poured upon it, thus condensing the vapor in the flask and thereby reducing the pressure, the water will boil.

In the manufacture of sugar, vacuum pans are used in which the boiling point of the syrup is lowered by reducing the pressure, thus avoiding the danger of burning the sugar.

On the other hand, in the extraction of glue from bones, the pressure is increased and the boiling point of the liquid correspondingly raised.

210. Relation of Altitude to Boiling Point. Since atmospheric pressure decreases with the elevation, the boiling point of a liquid also decreases. The boiling point of water may therefore be used to indicate the height of a place above the sea level. A decrease of 1°C in the boiling point indicates an elevation of 295 meters, or about 968 feet.

EXERCISE. 15. The boiling point of water at sea level is 100°C ; on Pike's Peak it is 85.4°C . Find the elevation of Pike's Peak above sea level.

211. Summary. The facts with respect to boiling as presented in the preceding topics may be summarized briefly in the following statements:

1. *Every liquid has a definite boiling point which is invariable under the same conditions.*
2. *An increase of pressure raises the boiling point; a decrease of pressure lowers the boiling point.*
3. *Salts dissolved in a liquid raise the boiling point; gases dissolved in a liquid lower the boiling point.*

TABLE XVII

BOILING POINTS

Alcohol.....	78° C	Glycerine.....	290° C
Ammonia.....	38	Mercury.....	357
Benzene.....	80	Toluene.....	110
Carbon disulphide.....	46	Turpentine.....	160
Chloroform.....	61	Water.....	100

212. Vaporization. The process by which a substance changes to a vapor is called *vaporization*. It may take place by boiling, by evaporation, or by sublimation. Vaporization takes place at all temperatures, even below the freezing point. It has been found that a block of ice, if left for a few days at a temperature below zero, will lose considerably in weight by vaporization; clothing hung out to dry on a cold winter's day will dry though frozen.

Evaporation is the process by which a liquid changes quietly at the surface to a vapor state.

Sublimation is the process by which a solid changes directly to a vapor without passing through the liquid state. If a piece of ice, for example, be placed under the receiver of an air pump, and the pressure be reduced to 4 millimeters or less, the ice on being heated will not liquefy, but will pass directly from the solid state to a vapor; that is, it will sublime. If the pressure be above 4 millimeters, it will liquefy. Camphor and arsenic will sublime at atmospheric pressure. These substances may be liquefied by sufficiently increasing the pressure upon them. Since arsenic sublimates at atmospheric pressure it is considered detrimental to health to use wall paper which contains any considerable amount of arsenic in the coloring matter.

213. Rate of Evaporation. The rate at which evaporation goes on depends upon four factors: (a) The extent of the free surface of the liquid, (b) the temperature, (c) the pressure exerted upon the surface of the liquid, and (d) the degree of saturation of the space above the liquid.

It is a familiar experience that if a given quantity of water be placed in a broad shallow dish it will evaporate much more quickly than if placed in a deep narrow dish; and also that the higher the temperature, the more rapid is the rate of evaporation. The drying of roads and streets after a rain illustrates the effect of a change of air on the rate of evaporation. If after a rain there be no wind, the air soon becomes saturated and evaporation is retarded; if, however, the air be in motion, evaporation goes on rapidly and the roads soon become dry. Damp clothes hung out to dry on a windy day also illustrate the case in point.

The rapid evaporation of liquids in "vacuum" pans due to diminished pressure is an application of the principle that the rate of evaporation is increased by decreasing the pressure.

The facts stated in the foregoing paragraphs may be summarized as follows:

1. *The rate of evaporation increases with the free surface of the liquid.*

2. *The rate of evaporation increases with the increase of temperature.*

3. *The rate of evaporation increases with a change of air in contact with the liquid.*

4. *The rate of evaporation increases as the pressure diminishes.*

214. Heat of Vaporization. If heat be applied to water the temperature rises until it reaches the boiling point. Further application of heat produces no further rise of temperature, the additional heat being used in changing the water from the liquid to the vapor state. *Heat of vaporization* is the heat required to change unit mass of a substance from the liquid to the vapor state without changing its temperature. The heat required to change one gram of water at 100° to steam at the same temperature is 538 calories; hence we say that *the heat of vaporization of water at 100° C is 538 calories per gram.*

The high heat of vaporization of water explains the value of steam heat as a means of heating buildings. Every gram

of steam that changes from steam at 100°C to water at the same temperature gives up 538 calories of heat.

When a liquid evaporates into the space above it, the vapor thus formed exerts a pressure. *Vapor pressure* is the pressure which is exerted by an unsaturated vapor. *Vapor tension*, on the other hand, is the pressure exerted by a vapor which is saturated, that is, a vapor which is in contact with its liquid. Each liquid has its own definite vapor tension for a given temperature. If a tube 80 centimeters in length be filled with mercury and inverted in a dish of mercury, Fig. 222, a Torricellian vacuum, v , results. Now introduce into this tube at the bottom, by means of a glass pipette, a few drops of water which being lighter than the mercury rise in the tube to the surface, and a portion of it evaporates. The water vapor thus liberated in the space above the mercury exerts a pressure which forces the column of mercury down to a certain point b . The difference between the height of the column a and that of b represents in centimeters the vapor tension of water at the given temperature. Now if the tube be forced down into the mercury as shown in c , some of the vapor will liquefy, but the mercurial column will stand at the same level as before. The vapor tension of a liquid is the same whether the space above the mercury be great or small, provided there is some free liquid present.

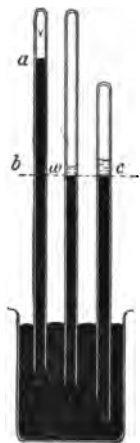


FIG. 222
Vapor pressure apparatus

215. Humidity. There is in the air at all times a certain amount of water vapor. At 20°C (68°F) a cubic meter of space when saturated contains about 17 grams of water vapor. The presence of air in the space does not appear to affect the amount of water vapor which it can contain. That is, a cubic meter of space at 20°C will contain 17 grams

of water vapor, whether it contains air at the same time or not.

Humidity is a term which is used to indicate the quantity of water vapor in the air. When the air contains all the water vapor it can at a given temperature it is said to be saturated. At 20° C, for example, air is saturated when it contains 17 grams of water vapor per cubic meter.

Relative humidity is the ratio of the amount of water vapor in the air at a given time to the amount that would be present if it were saturated. Relative humidity is usually expressed in terms of per cent; thus when we say that the relative humidity is 50, we mean that the air contains 50 per cent of the water required to saturate it at that temperature.

TABLE XVIII

NUMBER OF GRAMS OF WATER VAPOR REQUIRED TO SATURATE THE AIR,
PER CUBIC METER

0° C.... 4.835 g	10° C.... 9.330 g	20° C.... 17.118 g
1° 5.176	11° 9.935	21° 18.143
2° 5.538	12° 10.574	22° 19.222
3° 5.922	13° 11.249	23° 20.355
4° 6.330	14° 11.961	24° 21.546
5° 6.761	15° 12.712	25° 22.796
6° 7.219	16° 13.505	26° 24.109
7° 7.703	17° 14.339	27° 25.487
8° 8.216	18° 15.218	28° 26.933
9° 8.757	19° 16.144	29° 28.450

Example. On a given day when the temperature was 23° C it was found that the air contained 14.25 grams of water vapor per cubic meter. Find the relative humidity. *Solution:* On consulting the table we find that air at 23° C is capable of holding 20.355 grams of water vapor per cubic meter. The relative humidity is therefore $14.25/20.355 = 70$ per cent.

EXERCISE. 16. A given quantity of air at 20° C contains 10.2 grams of water vapor per cubic meter. What is the relative humidity?

216. Dew Point. Place a thermometer in a test tube partly filled with ether, Fig. 223. By means of a bent glass tube blow gently through the liquid a stream of air bubbles which will cause the ether to evaporate rapidly, thus producing a fall in temperature, as indicated by the thermometer. As the temperature falls, a point will be reached at which moisture or dew, condensed from the surrounding air, will appear on the outside of the tube. The temperature at which this moisture appears is called the dew point. In other words the *dew point* is the temperature at which the water vapor of the air reaches saturation and begins to condense.

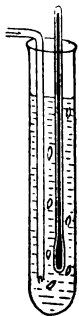


FIG. 223
Dew point
apparatus

Suppose, for example, that the air on a given day when the temperature is 20°C contains 12.7 grams of water vapor per cubic meter. Now it has been found by experiment (Table XVIII) that the saturation temperature for 12.7 grams per cubic meter is 15°C . This means that if the temperature of the air fall to 15°C , water will be precipitated in the form of dew. In other words, for 12.7 grams of water vapor per cubic meter, 15°C marks the dew point.

Fogs, clouds, and rain result from a lowering of the temperature below the dew point.

217. Distillation. *Distillation* is a process of separating one liquid from another or of separating a liquid from impurities by heating the mixture in one vessel and condensing

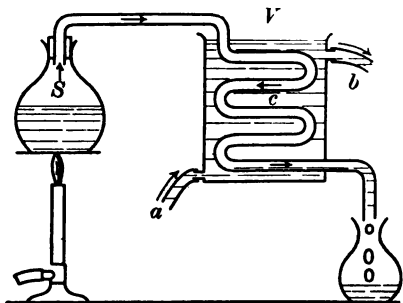


FIG. 224.—Distilling apparatus

the vapor in another. One form of distilling apparatus is shown in Fig. 224. Suppose that some water be placed in the vessel

S, called the still, and heated. The vapor passes through the coiled tube called the worm. The vessel *V* is filled with cold water entering at *a* and leaving at *b*, which condenses the vapor in the coil *c*, from which the pure water drops into the receiver *R*. The liquid which is collected in this receiver is called the distillate.

By means of this process of distillation pure water may be obtained from impure, and also one liquid may be separated from another, as for example, commercial alcohol from water, in which case alcohol, being the more volatile, distils over more readily than the water. Mercury is often distilled in order to separate it from its impurities.

THE TRANSMISSION OF HEAT

218. Introductory. We wish now to consider the subjects of keeping foods cool and of keeping buildings warm and comfortable, in other words, the subjects of refrigeration and of heating and ventilation. In order to do this, however, we must first study the subjects of conduction, convection, and radiation, that is, the transmission of heat from one body to another. Heat may be transmitted from one point to another in three ways: (a) by conduction, (b) by convection, and (c) by radiation.

Conduction is the transmission of heat through a body from molecule to molecule, as in the heating of a piece of iron in a flame. The heat is transmitted from one end of the iron to the other by conduction.

Convection is the transmission of heat by means of a current as, for example, winds and ocean currents. The Gulf Stream is an example of a convection current.

Radiation is a transfer of energy through space by means of waves set up in a hypothetical medium called "ether." The earth is thus heated by radiation from the sun.

219. Conductivity of Solids, Liquids, and Gases. *Solids.* The conductivity of solids varies over a wide range. Metals

are good conductors of heat; wood, on the other hand, is a poor conductor. The relative conductivity of metal and wood may be shown by wrapping a piece of paper around a cylinder, Fig. 225, one half of which is composed of metal and the other of wood. If now the cylinder be held in a flame, the paper will char where it touches the wood. It will not be burned, however, where it is in contact with the metal, due to the fact that the metal conducts the heat away so rapidly as to keep the paper below the burning point.

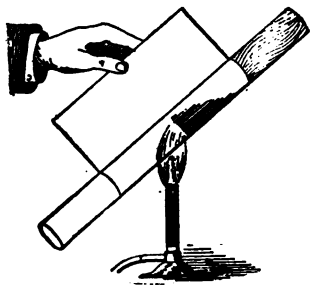


FIG. 225.—Metals are good conductors; wood is a poor conductor

Liquids. Liquids are poor conductors of heat, the conductivity of water, for example, being about $1/1000$ of that of silver, which is sometimes taken as a standard for the conductivity of metals.

Fasten a piece of ice in the bottom of a test tube nearly full of water. Hold the upper part of the tube in a flame, Fig. 226. In a short time the water in the top of the tube will begin to boil, thus giving boiling water, tepid water, and ice water all in the same vessel.

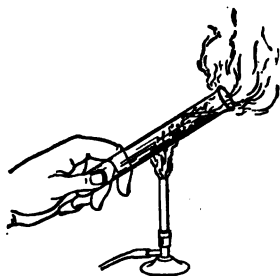


FIG. 226.—Liquids are poor conductors of heat

Gases. Gases are extremely poor conductors of heat. Woolen clothing owes its nonconducting properties partly to the fact that the wool fibre is a poor conductor, but more largely because of the nonconducting property of the air enclosed within it. The fur of animals is an effective protection from cold for the same reason. The air spaces between double windows and between the walls of houses are also

illustrations of some of the uses made of the nonconducting properties of gases.

220. Nonconductors in the Household. Aside from the use of cotton and wool in clothing, bedding, etc., there have come into common use in recent years two special household devices the operation of which depends upon the nonconducting properties of the materials of



FIG. 227
Fireless cooker

which they are made; we refer to the fireless cooker and the thermos bottle.

Fireless cooker. This device, Fig. 227, consists usually of a wooden box containing a number of receptacles designed to receive the food to be cooked. Around these vessels there is closely packed some material, such

as hay, felt, asbestos, or other nonconducting material, which encloses within its interstices nonconducting air. The food to be cooked is heated to the boiling point and then placed in

the receptacles within the cooker and carefully covered. Due to the nonconducting property of the packing material, and especially to the air enclosed within its spaces, sufficient heat is retained in the food until it is cooked. The effi-

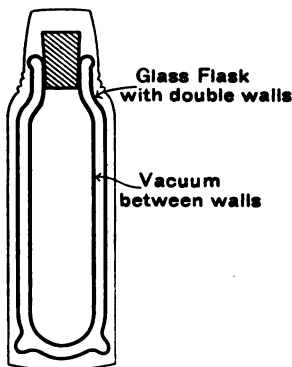
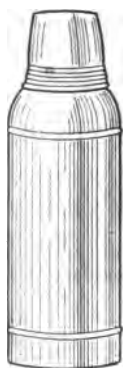


FIG. 228—Thermos Bottle

ciency of the apparatus depends of course upon the retention of the heat imparted to the food before it is placed in the cooker.

Thermos bottle. The thermos bottle or "icy-hot" bottle, Fig. 228, differs from the fireless cooker in that it is designed to keep heat in or out, as desired. It consists of two bottles blown one inside the other and sealed together. The outside of the inner bottle, and the inside of the outer bottle are silvered. The air is exhausted from the space between the bottles, and this space is sealed airtight.

It will be remembered that there are three ways in which heat is transmitted from one place to another, namely, by conduction, by convection, and by radiation. It is difficult for heat to enter or leave the bottle in any of these three ways. The evacuated space between the walls is an almost perfect nonconductor of heat. Also since the bottle is tightly closed no convection currents can occur. And finally, heat energy cannot be transmitted through the sides of the bottle by radiation because when the heat waves reach the bottle they are reflected by the bright silvered surface in the same way that light is reflected by the surface of a mirror.

221. Convection. *Convection* has been defined as the transmission of heat by currents. A good illustration of convection currents is given in Fig. 229, *I* and *II*. In Fig. *I* the convection current rises from the hot portion of the beaker, the colder and therefore denser water at *CC* forcing it upward. In Fig. *II* the reverse motion of the convection current is depicted.

An explanation of convection may be given somewhat as follows: When a given mass of

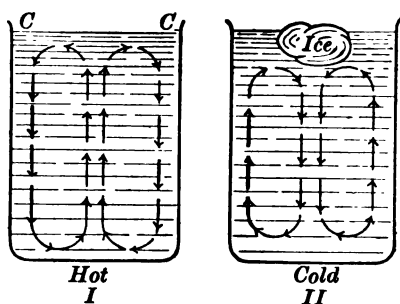


FIG. 229.—Convection currents

a fluid, air or water, is heated, it expands and its density diminishes. The surrounding medium being the heavier tends,

therefore, to displace the warm and relatively light fluid, forcing it upward. As the warm current rises it carries heat with it. Thus it appears that a fluid which is heated does not rise of its own accord, but is forced upward by the colder and heavier medium surrounding it.

222. Radiation. We have defined *radiation* as the transmission of energy by means of ether waves. All space is supposed to be filled with a medium called ether, which is assumed to have the properties of transmitting energy by means of waves. For example, energy is transmitted from the sun to the earth by radiation. It is important to note in this connection that in the transmission of energy from the sun to the earth the intervening space is not heated, and therefore we cannot properly speak of this radiant energy as heat. It is true that the waves by means of which energy is transmitted may have their origin in a heated body, the sun, and when they fall upon the earth they may give rise to heat, which is transmitted from point to point through the medium of matter by conduction or convection.

It must not be thought, however, that the sun is the only source of radiant energy. All hot bodies may lose heat by conduction, convection, and radiation. The important point to be kept in mind is that radiation is a transference of energy, which when expended upon matter may give rise to heat.

An illustration of the distinction between conduction, convection, and radiation may be given as follows: A fire is built in a grate or fireplace. In a short time all parts of the grate in contact with the fire become heated by conduction. Second, a draft of hot air sweeps up the chimney; the interior of the chimney is heated by convection. Finally, one sits before the fire. Notwithstanding the fact that currents of air are directed from the person toward the open fireplace, one experiences a sensation of warmth. Heat is transmitted from the fire to the person by radiation.

223. Transmission and Absorption of Radiant Energy.

Some substances allow radiant energy to pass through readily. Rock salt transmits radiant energy the most readily of any substance known. Other substances do not transmit radiant energy readily but absorb it. Lampblack absorbs radiant energy to a greater degree than any other substance known.

Radiant energy as has been stated is assumed to be transmitted by means of ether waves, some of which are long and some are short. Some substances like glass and water allow short waves to pass through readily, but absorb the long waves. Radiant energy comes from the sun to the earth in the form of both long waves and short waves. Now the atmosphere surrounding the earth contains enormous quantities of water vapor, which transmits the short waves and shuts off the long waves. These short waves on striking the earth heat it, and thus give rise to long waves, which are prevented by the water vapor in the atmosphere from passing out into space. Thus the water of the atmosphere serves as a sort of protecting blanket, which by shutting out the long waves keeps our days from being excessively hot, and by preventing too rapid radiation, keeps our nights from being excessively cool.

The hot house has been called, and quite rightly, a trap to catch sunbeams. The short waves of radiant energy pass readily through the glass and falling upon the interior heat it. Now the heat thus generated gives rise to long waves which cannot pass through the glass, their energy being thus entrapped, so to speak. That glass allows short waves to pass and not long waves may be seen when we consider the fact that the short waves conveying radiant energy from the sun pass readily through the glass of windows, and falling on our bodies give rise to heat. On the other hand it is a well known fact that if a glass screen be placed in front of a grate fire it will effectively shut off the heat; that is, it will prevent the transmission of the long waves conveying radiant energy from the fire.

224. Illustration of the Absorbing Power of Lampblack.
To show that lampblack absorbs radiant energy to a greater

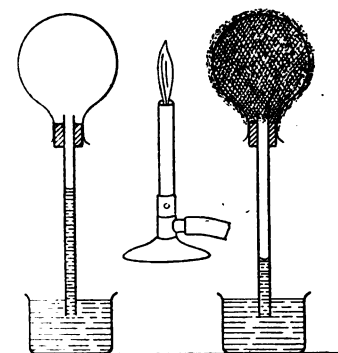


FIG. 230.—Illustrating the absorbing power of lampblack

degree than does glass, take two air thermometers as shown in Fig. 230 and coat the bulb of one of them with lampblack from a candle flame. Adjust the colored liquid to about the same height in both stems. Now place a hot body, such as a Bunsen flame or a sheet of hot iron midway between the bulbs. The radiation from the hot body passes quite readily through the glass bulb, but is absorbed by the blackened

bulb, as is shown by the lowering of the colored liquid in the tube.

225. Absorption and Reflection of Radiant Energy. The amount of radiant energy absorbed or reflected by a body depends upon (a) the temperature of the body and (b) the nature of its surface. In general a rough black body is a good absorber but a poor reflector of radiant energy; a smooth bright body, on the other hand, is a poor absorber but a good reflector.

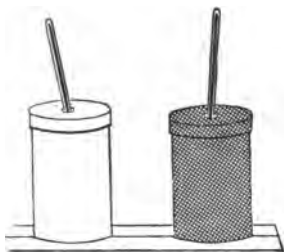


FIG. 231.—A bright body is a good reflector and a poor absorber of radiant energy

To determine the relative radiating power of a black body as compared with that of a bright body, take two bright tin cans (baking

powder cans from which the wrappings have been removed will do) and punch a hole in the cover of each for the admission of the thermometers, Fig. 231. Coat one of the cans

heavily with lampblack. Fill both with hot water and note the temperature of each at the beginning of the experiment. After a time again observe the temperature of the water in each can. It will be found that the water in the black can is considerably cooler than that in the bright one. A rough black body radiates more readily than a smooth bright body.

Again fill both cans with cold water and insert the thermometers. Place the cans in the sunshine, or at equal distances from a radiator. Note the temperature at the beginning of the experiment and at the end of half an hour. The water in the black can will be the hotter by several degrees. A rough black body is a better absorber of heat than is a bright polished body.

EXERCISES. 17. If a piece of black cloth and a piece of white cloth be placed in the sunshine upon the surface of snow in winter, which will settle into the snow the more rapidly?

18. Should cans used in shipping milk in summer be bright or dark in color, and why?

19. Which is the warmer in winter, a shoe that is polished or one that is not polished, other things being equal?

REFRIGERATION

228. Introductory. In modern life the problem of keeping food and buildings cool is almost as important as the problem of heating and ventilation. The preservation of food by the cold storage system, as well as the manufacture of artificial ice, involves an outlay of millions of dollars annually. The artificial cooling of buildings, such as hotels and auditoriums, is today receiving much attention by builders and designers.

There are two general methods of securing refrigeration, (a) by natural means, such as the use of ice, and (b) by the production of cold by artificial means. We shall first consider the method of producing cold by the use of ice. In order to cool food to about 50°F (10°C) and keep it at this temperature heat must be absorbed. This is conveniently done by

allowing the food to supply the heat to melt the ice. When ice is melted the amount of heat absorbed is equal to 80 calories per gram or 143 B. t. u. per pound of ice consumed. If the price of ice is 50 cents per 100 pounds the cost of absorbing heat is about 10 times the cost of producing heat by burning city gas at \$1.50 per 1000 cubic feet. Unfortunately the melting of ice cannot be shut off as can a gas flame. This fact makes it especially important to prevent as far as possible heat from getting to the ice. To do this we enclose the ice in a properly constructed refrigerator or ice box having well insulated walls.

227. The Ice Box. The inner chamber of an ice box is usually made of galvanized or enameled metal. The outer casing is made of wood, which is a good nonconductor of heat. Between the outer and inner casings there is a nonconducting air space. The ice box contains a number of compartments, one for the ice and the others for food which it is desired to keep cool. The ice is placed in a compartment near the top of the box. The air next the ice becomes cool and sinks through the openings in the ice chamber into the main part of the refrigerator, while the warmer air is forced upward where it comes in contact with the ice and there becomes cool. There is thus a continuous circulation of air through the ice chamber and down into the food compartment. This circulation is important because by this means the cooled air is distributed to all parts of the refrigerator, and also because on passing the ice the air loses some of its moisture and consequently some of the odors which it has taken up from the food. It follows, therefore, that anything which retards this circulation interferes seriously with effective refrigeration.

Investigation by the U. S. Department of Agriculture has shown that in milk kept at 60° F about 15 times as many bacteria will develop in a day as in milk kept at 50° F. It is important, therefore, that such foods as milk and meats

should be kept in the coldest part of the ice box, which is the part immediately below the ice, Fig. 232, *I* and *II*.

Slow melting of the ice does not necessarily indicate a good refrigerator. Unless the ice melts it can absorb no heat and it is therefore of no use as a cooling agent. Protecting the ice in a refrigerator by covering it with cloth or paper is a good way to save ice but a poor way to save food.

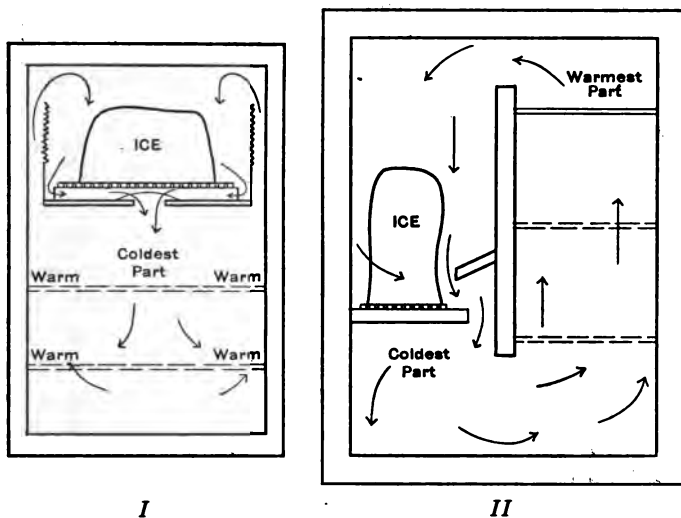


FIG. 232.—Diagram showing the circulation of air in refrigerators. Milk, butter and meat should be kept in the coldest part, which is just below the ice

The only proper way to economize in ice is to use a refrigerator with better insulating walls, and by opening the doors as seldom and for as short a time as possible. In order that the efficiency of an ice box be high the following conditions should be noted: (a) The insulation should be as perfect as possible. (b) The ice chamber should be kept full. (c) Doors should be kept closed as much as possible. (d) The drainage tube should be kept closed by means of a water trap, Fig. 160, Art. 140.

228. Production of Cold by Artificial Means. The production of cold by artificial means is today of great commercial importance. There are three methods of producing cold artificially: namely, (a) by solution; (b) by evaporation; (c) by expansion of gases. The fundamental principle involved in these three methods is the same; that is, each process involves the expenditure of energy, which in turn involves the absorption of heat. When, for example, salt dissolves in a liquid, or a liquid evaporates, or a gas expands, energy in the form of heat is taken and a condition of cold is produced.

229. Cold by Solution. When a lump of sugar is dropped into a cup of coffee, the temperature of the coffee is lowered slightly as the sugar dissolves, due to the fact that the dissolving of the sugar takes energy from the liquid in the form of heat. In general the solution of crystalline substances in liquids tends to lower the temperature, although in some cases this lowering of temperature is masked by secondary chemical reactions. If a mixture of 2 parts by weight of ammonium nitrate (NH_4NO_3) and 1 part of ammonium chloride (NH_4Cl) be put into a beaker of water at room temperature and stirred gently with a thermometer, it will be observed that the temperature of the water will fall several degrees. The dissolving of the salt takes energy from the water in the form of heat, thus causing the fall in temperature.

230. The Ice Cream Freezer. The common ice cream freezer is one of the best known devices for producing cold by artificial means. The principle employed is that of the production of cold by solution. The cream to be frozen is placed in a metallic vessel *A*, Fig. 233, in which a stirrer is rotated by means of a crank *C*. Around this vessel there is packed a mixture of salt and crushed ice, *B*. The contact of the salt with the ice tends to cause the latter to melt, and the resulting liquid dissolves the salt, both operations absorbing heat, which is withdrawn from the cream in the

vessel A. The object of stirring the cream is to bring all portions of it successively in contact with the walls of the containing vessel, causing it to freeze uniformly. It is important to note that the cream freezes when the ice melts; that is, the melting ice absorbs heat, which is furnished by the cream.

It has been found by experiment that the best mixture of ice and salt for producing a maximum lowering of temperature is 3 parts of ice to 1 part of salt by weight.

231. Cooling by Evaporation. When a liquid evaporates energy in the form of heat is required to separate the molecules.

Evaporation is, therefore, a cooling process. A gram of water at 20°C (ordinary room temperature) in changing from a liquid to a vapor takes up 582 calories.

If some highly volatile liquid as ether be dropped upon the bulb of an air thermometer, Fig. 234, the colored liquid in the stem will quickly rise, due to the chill produced by the rapid evaporation of the ether, resulting in a contraction of air within the bulb. Sprinkling the floor with water in the summer cools the air in the room because of the heat absorbed



FIG. 234
Air
thermometer

by the evaporation of the water.

Fill a small porous battery jar with water and place in the vessel a thermometer, Fig. 235, noting the temperature at the beginning of the experiment. In the course of fifteen minutes the temperature of the water will have fallen considerably, due to evaporation from the sides of the jar. In some warm countries, as Mexico, water is often cooled by

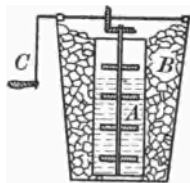


FIG. 233
Ice cream freezer



FIG. 235
Evaporation
through porous
jar producing
a cooling effect

placing it in large porous vessels, which allow evaporation to take place over the entire surface.

232. Cold by Expansion. When a gas expands it does work on the surrounding medium; the energy thus expended comes from the gas in the form of heat, and as a result the temperature is lowered. The cooling effect of an expanding gas may be strikingly illustrated in the following manner. Obtain a tank of liquid carbon dioxide, such as is used in soda fountains. The carbon dioxide in the tank is under



FIG. 236.—Carbon dioxide snow

enormous pressure. If now the stop cock connected with the tank be opened and the gas within allowed to expand, there will result a lowering of the temperature, due both to the vaporization of the liquid and also the expansion of the gas. The chill produced is sufficient to freeze the carbon

dioxide, which appears in the form of a white mist or snow, Fig. 236.

The temperature of solid carbon dioxide at atmospheric pressure is -78°C .

233. The Ice Machine. In the operation of the modern commercial refrigerating apparatus a reduction of temperature is obtained by the evaporation and expansion of liquid ammonia. Gaseous ammonia is especially suitable for this purpose because it may be liquefied by compression alone at ordinary temperatures. At 27°C (80°F) a pressure of 155 pounds per square inch is required.

The principle of the ice machine may be illustrated by means of a very simple apparatus shown in outline in Fig. 237. A cylinder *AB*, which is provided with a piston and which contains some liquid ammonia under high pressure, is placed in the water to be frozen. The piston is suddenly drawn up, thus reducing the pressure upon the liquid. The am-

monia in *A* evaporates and expands into *B*, producing a chill, and thus tending to freeze the water in *C*. The lowering of the temperature is produced by both the evaporation and the expansion of the ammonia. In actual practice the machine is very much more complicated, as shown in Fig. 238.

The pressure pump *P* is provided with two valves, one opening upward and the other downward. Liquid ammonia is placed under high pressure in the coils *A*, which are kept cool by means of a stream of cold water playing over them. The liquid ammonia is then allowed to expand into the cooling tank *C*, which contains brine, through the valve *V*. As

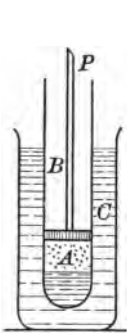


FIG. 237

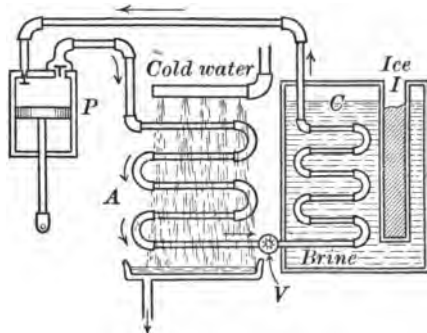


FIG. 238

Ice machine

the ammonia expands (changes from a liquid to a gas) in the tubes of chamber *C*, heat is absorbed from the brine, reducing its temperature to about -10°C . Ice cans *I* containing pure water are suspended in the cold brine. The water in the cans freezes, forming a solid block.

When it is desired to cool a storage room in a house, hotel, steamship, or cold storage warehouse, the brine is pumped from the tank *C* to coils of pipe placed near the ceiling of the room. The brine is kept circulating between the tank and the coils, thus cooling the cold storage room in the same manner as the block of ice cools a refrigerator.

234. Extremely Low Temperatures. The production of extremely low temperatures is attained by the method of evaporation and expansion. In order to make liquid air, for example, the air is compressed in a vessel *A* and cooled, and then allowed to expand into a second vessel *B*. The expansion reduces its temperature. This cold air is compressed and cooled and again is allowed to expand. The process of compressing, cooling, and expanding is continued until the liquefying point is reached. In modern liquid air machines air can be reduced to a liquid state at a temperature below -140°C in a few minutes.

Air is a mechanical mixture of nitrogen and oxygen. The boiling point of liquid nitrogen is -195°C and that of liquid oxygen -183°C ; that is, the boiling point of nitrogen is lower than that of oxygen. When air is liquefied, therefore, and allowed to stand in a flask, the nitrogen will boil off first. After the flask has stood for some time, the nitrogen will have boiled away and the liquid left will be oxygen.

By evaporation and expansion methods nearly all gases have been liquefied. By boiling the gas helium under reduced pressure a temperature of -270°C has been reached. This is within 3° of absolute zero.

TABLE XIX

EXTREMELY LOW FREEZING AND BOILING POINTS

	Freezing Point	Boiling Point
Nitrogen.....	-210°C	-195°C
Oxygen.....	-227	-183
Hydrogen.....	-259	-258
Helium.....	-270	-269

FUELS AND COMBUSTION

235. Introductory. Fuels may be classified roughly as solid fuels, liquid fuels, and gaseous fuels. The solid fuels in common use today are wood, charcoal, coal, and coke;

liquid fuels, petroleum, refined oils, such as kerosene and gasoline, and alcohol; gaseous fuels, natural gas, manufactured gas, and acetylene.

The heat generated by an electric current will be discussed in the chapter on Electricity.

Fuels are burned in air. Burning or combustion is due to the chemical reaction between the elements composing the fuel and the oxygen of the air. For example, when carbon (C) burns in oxygen (O), the following reaction takes place: $C + 2O = CO_2$; that is, one atom of carbon unites with 2 atoms of oxygen to form one molecule of carbon dioxide. In this connection the point to be borne in mind is this: In order that perfect combustion take place it is not only necessary to supply fuel (carbon or carbon compounds) but it is of equal importance that an adequate supply of oxygen be available. When the air drafts of a stove or furnace are closed the fire dies down because the supply of oxygen is inadequate to support combustion.

236. The Smoke Nuisance. If the air holes at the base of a Bunsen burner are open the gas burns with a colorless flame, which indicates perfect combustion; if the holes are closed the flame is yellow and smoky, due to imperfect combustion. Also, if the wick of a kerosene lamp be imperfectly trimmed or turned up too high the lamp smokes; this is an excellent illustration of imperfect combustion. Smoke is always an indication of imperfect combustion; it also indicates a waste of fuel, because smoke consists mainly of particles of unburned carbon.

Smoke not only represents a waste of fuel amounting annually to millions of dollars, but in many of our cities it has become a nuisance so serious that stringent laws have been enacted looking toward its abatement. Pittsburgh furnishes an example not only of the smoke evil at its worst, but also of what may be done to mitigate it. Exhaustive studies of the subject were made in that city by the Mellon Institute

of Industrial Research. Measurements of sootfall made at twelve stations in Pittsburgh in 1912-13 indicated an annual average deposit of soot in that city of more than 1000 tons per square mile. In Leeds, a manufacturing town in England, the sootfall ranges from 25 to 500 tons per square mile in different sections of the town. London's average is 248 tons per square mile for the whole city. It was found that the smoke evil was then (1912-13) costing Pittsburgh about \$10,000,000 per annum, not including depreciation in the value of property, absence of various industries which cannot flourish in a smoky atmosphere, and injury to human health. The smoke-makers themselves were losing \$1,520,740 which might have been saved by more perfect combustion of fuel. The laundry bills of the people were \$1,500,000 bigger than they would have been with a clean atmosphere, and their dry cleaning bills \$750,000 greater. Houses in Pittsburgh were, on an average, painted every three years, as compared with every five or six years in other cities. The sheet metal



FIG. 239.—A Pittsburgh steel plant before the installation of smoke consuming and fuel saving devices

of roofs, gutters, spouts, etc., deteriorated twice as fast in the smoky atmosphere as in an average large city, and needed painting twice as often. And in addition to all this the city was spending \$730,000 for artificial light in the daytime.

As a result of the collection and publication of these data, stringent smoke-abatement ordinances were adopted in 1914, and in the fol-

lowing year it was reported that the amount of smoke emitted had been reduced 75 per cent.

The first smoke abatement invention was patented by James Watt in 1785. Present day methods adopted to diminish smoke output include (a) changes from soft coal to gas, coke, and low volatile fuels; (b) installation of down-draft boilers; (c) steam jets and extension stacks; and (d) automatic stokers. An automatic stoker is a mechanical device for delivering the fuel to the furnace at a uniform rate and for distributing it evenly upon the grates. This favors complete combustion, thus increasing the heat energy derived from the fuel and at the same time decreasing the smoke output.

In Fig. 239 we have a view of the smoke issuing from the furnace of a steel plant in the Pittsburgh district before the installation of smoke consuming and fuel saving devices. The same plant as it looks today is shown in Fig. 240. Both plants are in full operation.

237. Heat of Combustion. The heat of combustion of a substance is measured by the number of units of heat given out when unit quantity of the substance is burned. The heat of combustion of fuel such as coal and illuminating gas may be expressed in calories or in British thermal units (B.t.u.). It has been shown



FIG. 240.—The same in full operation after the installation of smoke consuming devices

by experiment that the heats of combustion for wood, for coal of average grade, and for illuminating gas are about as follows:

ENGLISH UNITS	METRIC UNITS
1 pound wood, about.. 7,000 B.t.u.	1 gram wood, about 4,300 cal.
1 pound coal " 13,000 "	1 gram coal " 8,000 "
1 cu. ft. illuminating gas 600 "	1 gram illuminating gas. 6,000 "

238. Solid Fuels. Wood. Formerly wood was almost exclusively used in this country for heating and cooking purposes. Although wood has been almost entirely displaced as a fuel by coal, oil, and gas, it is worthy of note that nearly one hundred million cords are still burned annually in this country for fuel. Pound for pound the fuel value of wood is about half that of coal, while in most places the relative cost is very much greater.

Charcoal. Charcoal, made by the distillation of wood in kilns, burns without much flame and gives a good heat. It is popular in hotels where it is burned in small broilers, the food being served from the broiler as it would be from a chafing dish. Charcoal ignites easily and small pieces of it are frequently used for starting fires.

Coal. Coal is classified with reference to the volatile matter that it contains as bituminous or soft coal, semi-bituminous, and anthracite or hard coal. (a) A bituminous coal is one that contains over 20 per cent of volatile matter. This coal is used largely in the manufacture of gas. Hocking Valley coal is a type of bituminous coal of average grade, having a heat of combustion of about 14,000 B. t. u. per pound. (b) Semi-bituminous coal looks something like anthracite, but is lighter in weight and burns more readily. It is valuable where it is necessary to keep an intense heat. A high grade semi-bituminous is that known as Pocahontas, the heat of combustion of which is 15,000 B. t. u. per pound. (c) Anthracite or hard coal contains less than 10 per cent of volatile matter. It ignites very slowly and burns at a high temperature. Owing to its smokeless burning it is used almost altogether for domestic purposes. A good quality of anthracite coal, such as Scranton coal, has a heat of combustion of about 13,000 B. t. u. per pound.

Coke. Coke is obtained by the destructive distillation of soft coal. In many cities the main source of supply of coke is furnished by the gas plants. Soft coal is heated in retorts, and the volatile constituents are used in the manufacture of illuminating gas, or other products. The coke is the solid part of the coal; it consists mainly of pure carbon, with a small residuum of ash and other waste material. Coke is much lighter in weight than coal, and is much cleaner than the soft coal from which it is derived. It is superior to soft coal because it gives a hotter fire; but it is inferior to hard coal in that it burns more quickly and requires more attention.

239. Liquid and Gas Fuels. *Crude oils* are now used in increasing quantities as a source of heat for the engines of railroad trains and ocean going vessels. Kerosene is used in certain types of tractor engines, and sometimes for cooking. Occasionally portable oil stoves are employed for heating purposes. The use of oil stoves of this sort, however, is not to be recommended for heating living rooms because of the waste gases which they give off. If one sits for any length of time in a closed room heated by an oil stove which is not connected with a ventilating chimney, one is likely to suffer from headache and other ills.

Gasoline is derived from petroleum which occurs in Pennsylvania, Ohio, Oklahoma, Texas, and California. Enormous quantities of gasoline are used in automobile engines, and like power devices. The heating power of gasoline is about 19,000 B. t. u. per pound.

Gas fuels. The fuels of this group comprise natural gas and manufactured gas, commonly known as illuminating gas. In the economical use of gas as a fuel for cooking, gas stove burners should be so adjusted that the blue-green central part of the flame is about half the height of the whole flame. If the flame is very long and is yellow in parts, too little air is being admitted; if the flame is short and makes a slight roaring noise, too much air is being admitted. The

amount of air admitted to a gas burner is usually adjusted by means of a valve or damper situated at the base of the burner. In all gas burners the various openings should be kept clean.

240. The Oxy-Acetylene Flame. *Acetylene* (C_2H_2) is gas which results from the chemical reaction between calcium carbide (CaC_2) and water (H_2O). If crystals of calcium carbide are put into water a clear, colorless gas (acetylene)



FIG. 241.—Cutting an iron plate with an oxy-acetylene flame

is given off which burns with a brilliant white flame. Originally calcium carbide was expensive, but in 1892 it was discovered that it could be cheaply made by fusing lime and coal together in the intense heat of an electric furnace. As a result of this discovery, calcium carbide was soon made on a large scale and sold at a moderate price.

The *oxy-acetylene torch* is a device by means of which oxygen and acetylene, contained in metal tanks under high pressure, is mixed and burned. The oxy-acetylene flame is

exceedingly hot, and for this reason it is used for cutting iron and steel bars and plate, Fig. 241, and for welding purposes.

TABLE XX

COMPARISON OF HEAT VALUES OF FUELS

	B.t.u. per lb.		B.t.u. per lb.
Wood, soft.....	7,000	Fuel oil.....	18,000
Wood, hard.....	7,000	Kerosene.....	18,000
Coal, soft.....	14,000	Gasoline.....	19,000
Coal, hard.....	13,000		B.t.u.
Charcoal.....	16,000		per cu. ft.
Coke.....	12,000	Natural gas.....	1,000
Alcohol.....	12,000	Manufactured gas.....	600

241. Open Fireplace and Stove. Heating by means of an open fireplace has two things in its favor. First, the open fire gives to the room a cheery appearance, and second, it furnishes an excellent means of ventilation. A strong draft (convection current) up the chimney is created by the fire. This heated air is replaced by fresh air which finds its way in by doors and windows. Since the convection currents that are created are directed into the chimney, all the heat that gets out into the room must be transmitted by radiation. The amount of heat sent out into the room by radiation is small as compared with the quantity which is carried up the chimney. It follows, therefore, that this method of heating is a very wasteful one.

A stove is a more effective heating device than the open fireplace, because heat is transmitted to the room by conduction and convection as well as by radiation. The stove, however, must be classified as a low grade heating system because of its relatively poor heat transmission and also because it fails to possess adequate ventilating facilities.

242. The Furnace. The ordinary hot air furnace is in principle nothing but a stove surrounded by a jacket and

placed below the floor. The furnace has an advantage over the stove in that it may be more conveniently taken care

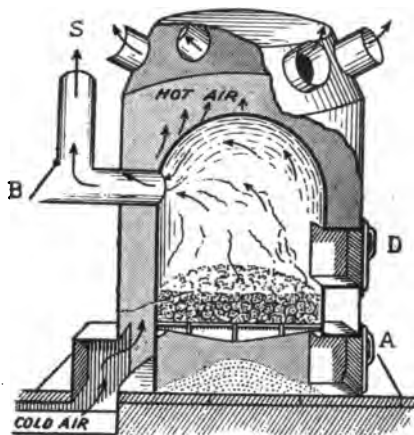


FIG. 242.—Hot air furnace

of because of its location in the basement. And another advantage lies in the fact that pure out-door air may be supplied to the rooms above it. Furnaces are usually supplied with a water pan which should be kept full so as to keep the heated air from becoming too dry. In operating a furnace the following conditions should be noted:

(a) It is good economy to keep the furnace well filled with fuel; that is, it is better to fill the furnace full once or twice a day than to put in smaller amounts several times during the day. (b) In burning coal the grates should be kept clean of ashes and clinkers. (c) If coke is used a bed of ashes may remain on the grates below the fuel. Since coke burns with a very intense heat, care must be observed in regulating the drafts. (d) For a hot fire, open draft *A*, Fig. 242, and close the check draft *B*; for a slow fire, close *A* and open *B*; for medium fire close both *A* and *B*. In the case of coke after the fire gets well started, close draft *A* and open *B*.

243. Use of Convection Currents in Heating.

Convection currents such as are used in hot water heating systems may be demonstrated by a simple device, such as is

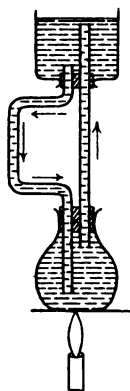


FIG. 243
Convection
currents

shown in Fig. 243. Fill the flask and tubes with water. Then add to the open vessel at the top some colored liquid. Now when heat is applied to the lower vessel the cold water in the tube descends and the hot water rises, thus giving rise to convection currents, the colored liquid showing very clearly their direction. The lower vessel corresponds to the furnace, the tubes to the pipes and coils of the heating system, and the upper vessel to the expansion tank which is usually located in the upper story of the house. In Fig. 244, there is shown

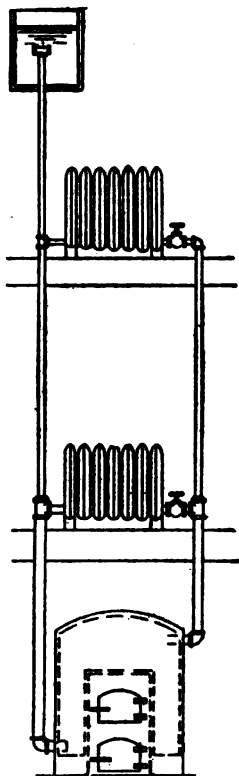


FIG. 244
Hot water heating system

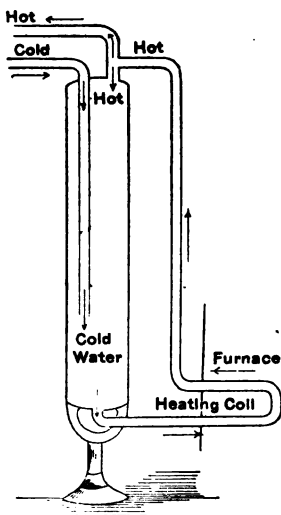


FIG. 245
Hot water tank

a hot water heating system, and in Fig. 245 a hot water tank such as is used in connection with the ordinary furnace to provide hot water throughout the house.

VENTILATION

244. Composition of the Air. The heating problem is closely associated with the problem of ventilation. In order to discuss this subject with some degree of intelligence we shall consider the composition of the air, since this is the medium which always enters into any scheme of ventilation. Air is composed of two gases, oxygen (O) and nitrogen (N) which occur in the approximate ratio of 1 to 4 by volume. In addition to oxygen and nitrogen the air also contains a small proportion of other substances, such as water vapor, ozone, carbon dioxide, smoke, dust, germs, etc.

Oxygen is the life-giving principle of the air. It supports combustion, whether it be in the case of a candle flame, the burning of wood in a grate, coal in a furnace, or the combustion of the waste tissues of the body. *Nitrogen* is an inert gas which serves to dilute the oxygen and thus prevent too rapid combustion. If the air consisted of pure oxygen, combustion would go on at a destructive rate. It can be shown that in undiluted oxygen even iron will burn. *Carbon dioxide* is a non-poisonous gas and a non-supporter of animal life and combustion. If one were placed in a tank filled with carbon dioxide he would be smothered as effectively as if he were drowned in water. While carbon dioxide is not in itself poisonous, yet it is usually taken as the measure of the impurities present in the air of a room due to respiration and other exhalations from the body. If there be a relatively large quantity of carbon dioxide present in a room, it is assumed that the air is impure. That carbon dioxide is given off from the lungs in respiration may be shown by forcing some air from the lungs through a small glass tube into clear lime water contained in a test tube. When the carbon dioxide comes in contact with the lime water a white precipitate of calcium carbonate (Ca CO_3) is formed. The degree of turbidity or milkiness of the lime water is taken as a test of the quantity of carbon dioxide present.

245. Relation of Humidity to Bodily Comfort. Next to oxygen and nitrogen, water is one of the most important constituents of the air, and the role that it plays is of major importance in relation to bodily comfort and health. To maintain a healthful and comfortable condition of the body it is necessary that air possess a relative humidity of about 60 per cent. The maintenance of about this degree of humidity is one of the objects of ventilation. If air is very dry, that is if the humidity is low, there results an uncomfortable condition of the body due to the excessive extraction of water from the skin, and especially from the mucous membranes of the respiratory tract. To illustrate how the humidity of the air changes with a change of temperature, let us consider the following example: Suppose that out-door air in winter, having a temperature of 0°C and a relative humidity of 80 per cent, is passed through a furnace and is heated to 20°C (68°F), and thence to a living room. The phenomenon which is most apparent to the ordinary person is the change in temperature of the air from 0° to 20°C . This, however, is by no means the most important change which has taken place with reference to the air. For example, the air enters the furnace at 0°C , 80 per cent saturated, and emerges at 20°C . Referring to Table XVIII, page 218, we find that a cubic meter of air at 0°C is capable of containing 4.8 grams of water vapor. A humidity of 80 per cent, therefore, will represent $4.8 \times 0.8 = 3.48$ grams of water vapor per cubic meter. Now the air is heated to 20°C , and its capacity for holding water is changed to 17 grams per cubic meter (Table XVIII). Since relative humidity is the ratio of water vapor in the air at a given time to the quantity required for saturation, the relative humidity at 20°C is $3.48/17 = 22.6$ per cent. This means that the humidity of the air in passing through the furnace was lowered from 80 per cent to 22.6 per cent. For health and comfort, however, air should possess a relative humidity of about 60 per cent. It is evident, there-

fore, that unless some special provision be made for adding moisture to the air when thus heated, the humidity will be far too low.

The proper degree of humidity not only prevents excessive moisture losses from the mucous membranes, but it is also an important factor in the regulation of temperature of the body. The temperature of the normal healthy human body is very nearly constant at 98.5° F. Now one of the most important agencies in the regulation of bodily temperature is that of evaporation. Evaporation is a cooling process. When it goes on freely the temperature is lowered; when it is retarded the temperature rises. When the air is filled with moisture, that is when the humidity is high, evaporation is retarded, and hence the temperature of the body rises. Now when the air is dry evaporation is accelerated and the body remains cool, even though the temperature is high. Thus it appears that our sensations of warmth and cold depend not only upon temperature but also on humidity as well.

246. Why We Ventilate. Scientific reasons for the necessity of ventilating rooms are not altogether clear. It was formerly supposed that the main object of ventilating was to furnish a supply of oxygen and to get rid of carbon dioxide. Experiments have shown, however, that unless the oxygen falls below 12 per cent and the carbon dioxide rises to 3 per cent, conditions which very rarely occur in human habitations, no marked discomfort ensues from the deficiency of oxygen or the excess of carbon dioxide. The fact remains, however, that unless the air in a room is frequently changed a healthy tone of the human body cannot be maintained. It seems, then, that the ill effects which arise from breathing vitiated air comes not so much from a deficiency of oxygen or an excess of carbon dioxide as from other causes, such as the presence of injurious gases, and faulty temperature conditions and moisture regulation. We ventilate, then, to supply pure

air and to remove impure air, and also to regulate temperature and moisture conditions.

It is estimated that the proper quantity of air, in cubic feet, that should be supplied per person per hour is about as follows: (a) hospitals, 5000; music halls and "movie" theaters, 3000; schools and churches, 2000.

247. Methods of Ventilating.

The fundamental principles governing ventilation may be illustrated by an experiment with a candle and a glass flask, Fig. 246. By means of a wire lower a small lighted candle into a flask having a rather wide neck. The flame

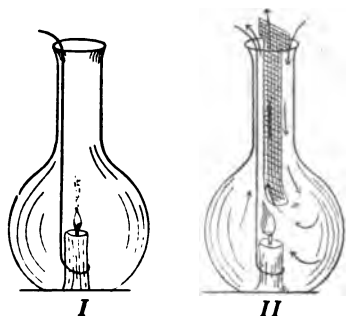


FIG. 246.—Ventilation illustrated

burns brightly for a while, and then begins to grow dim, and soon goes out due to the fact that the oxygen of the air within the flask is burned out. Now if a strip of tin or cardboard be thrust down into the neck of the flask and be so adjusted that a stream of cool air will descend on one side and a stream of hot air ascend on the other, we shall have the conditions necessary for the ventilation of the flask, and the candle flame will burn brightly.

Natural ventilation is that which takes place through the walls, cracks around doors and windows, and through the opening and closing of doors in passing from one room to another. Except



FIG. 247.—The inflow and outflow of air in a room

on windy days this method is not sufficient to keep the air of

most rooms in proper condition for breathing, and especially is this true of rooms where a large number of persons are congregated.

That a passage of air from room to room does actually take place may often be demonstrated, as shown in Fig. 247, by means of a candle flame. At the top of the door the flame is bent in one direction, at the bottom in another direction, thus showing that there is a draft of air into the room at the bottom and a draft out at the top.

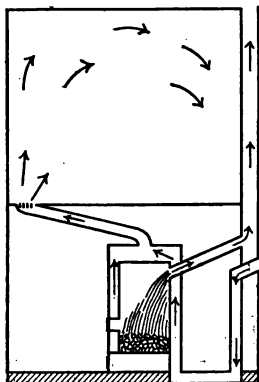


FIG. 248

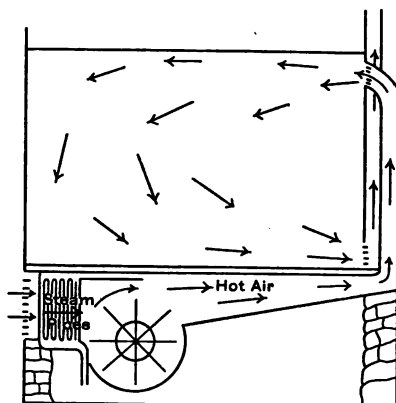


FIG. 249

Heating and ventilating systems

Ventilation by means of hot air furnaces, in which pure out-of-door air is heated and then passed into the rooms through registers is a fairly good method of ventilating buildings which are not too large, Fig. 248. In large buildings, however, such as auditoriums, the most economical and efficient method of changing the air is by means of mechanically driven fans, Fig. 249. Pure out-door air passes over a system of steam heated pipes and is then driven by the fan into rooms of the building, entering near the ceiling and leaving at a point in the same wall below the inlet.

GAS AND STEAM ENGINES

248. Joule's Experiment. The first accurate determination of the relation between heat and work was made in 1845 by Joule, an English physicist. His experiment was conducted somewhat as follows: A given quantity of water was placed in a vessel containing a paddle wheel, Fig. 250. About the axle of the wheel there was wound a strong flexible cord to the end of which was attached a weight, W . When the weight was allowed to fall, the work done, measured in foot pounds, was equal to the weight W in pounds times the space s . The falling of the weight caused the paddles to rotate,



James Prescott Joule

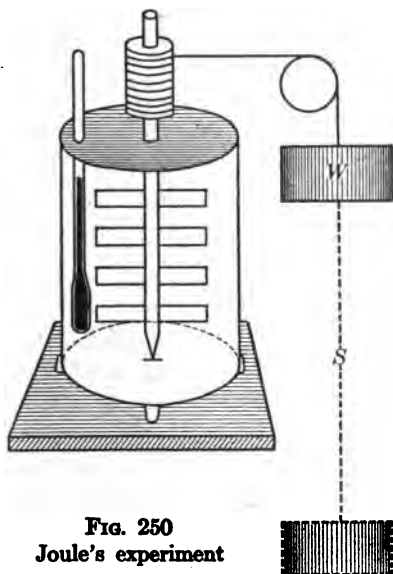


FIG. 250
Joule's experiment

thus doing the work upon the water and causing a rise in temperature. Joule's experiment demonstrates that a weight of 77.2 pounds falling through a distance of 10 feet (representing work to the amount of $77.2 \times 10 = 772$ F. P.) would raise the temperature of 1 pound of water 1° F. This means that a pint of water (1 pound, approximately) in cooling from the boiling point (212° F) to room temperature (70° F) would give out heat enough to do more than 100,000 foot pounds of work.

249. The Mechanical Equivalent of Heat. The relation of work units to heat units is called the mechanical equivalent of heat. In 1879 Professor Rowland of Johns Hopkins University, Baltimore, made a series of classical experiments with an improved form of Joule's apparatus, by means of which he determined the following values for the mechanical equivalent of heat:

$$1 \text{ calorie} = 4.19 \times 10^7 \text{ ergs}$$

$$1 \text{ B.t.u.} = 778 \text{ foot pounds}$$

250. The Gas Engine. The principle upon which the gas engine, Fig. 251, works is very simple. An explosive mix-

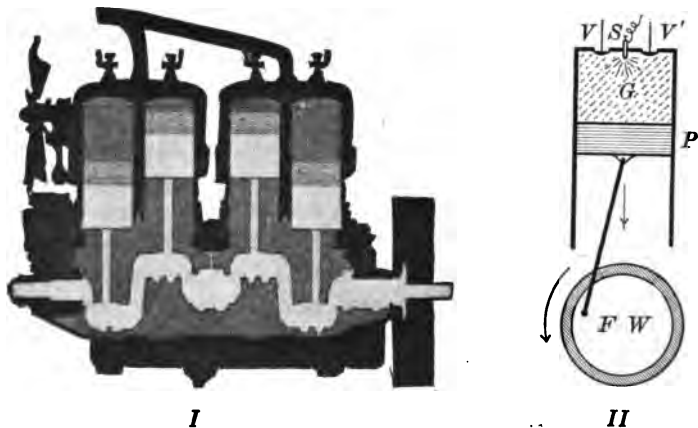


Fig. 251.—Outline section of a gas engine

ture of air and gas (vaporized gasoline or kerosene) is admitted to the cylinder *G*, Fig. 251 *II*, and is exploded by means of an electric spark at the spark plug, *S*. The explosion of the gas gives rise to a sudden expansion which causes the piston to move downward. The inertia of the flywheel carries the piston back to the upper end of the cylinder, where an explosion of the confined gas again takes place, these explosions being so timed as always to occur when

the piston is in the position shown in the figure. The gas is admitted to the cylinder through valve *V*, and the waste or exploded gas is expelled through valve *V'*.

In Fig. 252 there is represented the four steps of a four-cycle, single-cylinder gas engine. (a) First, the flywheel is turned by hand, or other device, causing the piston to move down and thus suck in a mixture of air and gas through the valve *i*. (b) As the flywheel continues its rotation, the piston moves back, compressing the gas. (c) The compressed gas

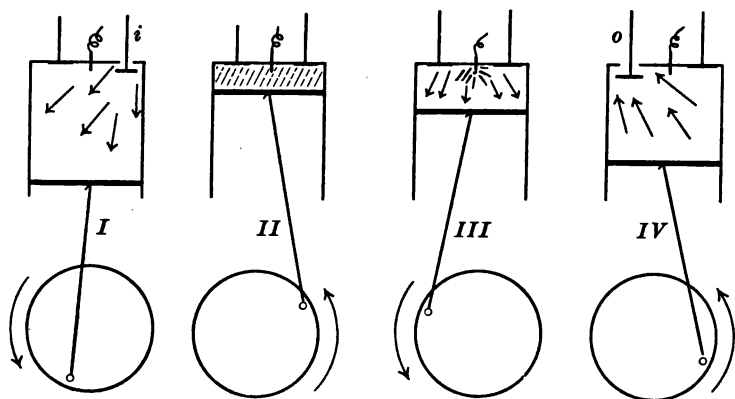


FIG. 252.—Illustrating the four steps of a four-cycle, single-cylinder gas engine

now explodes, driving the piston forward. (d) On the back stroke of the piston the burnt gases are ejected through valve *o*. To repeat, the four steps required to complete the cycle include the following: Downward stroke of piston and intake of gas; upward stroke of piston and compression of gas; explosion of gas, causing downward motion of piston; upward motion of piston and ejection of gas. The explosion of gas is due to an electric spark, which is timed to occur at the proper moment. Since the expanding gas acts on the piston during only one part of this entire operation, it is necessary in gas

engines to provide a heavy flywheel, the momentum of which is sufficient to operate the piston during the remaining three steps.

The gas engine just described is called a *four-cycle engine*; that is, it requires four strokes of the piston to complete the cycle. An engine making two strokes to the cycle is called a *two-cycle engine*.

251. The Carburetor. The *carburetor* is a device for converting liquid fuel, such as gasoline, into vapor and mixing

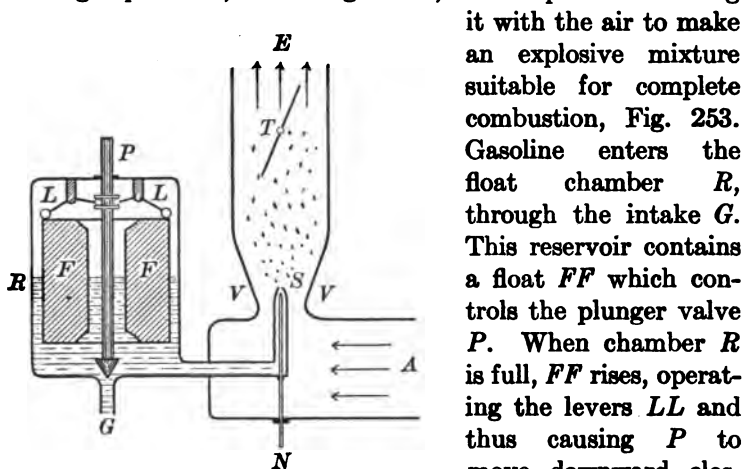


FIG. 253.—Outline section of a carburetor

it with the air to make an explosive mixture suitable for complete combustion, Fig. 253. Gasoline enters the float chamber *R*, through the intake *G*. This reservoir contains a float *FF* which controls the plunger valve *P*. When chamber *R* is full, *FF* rises, operating the levers *LL* and thus causing *P* to move downward closing the opening *G*. Air enters at *A*, and the mixture of air and gas flows to the engine through the opening *E*. The constricted part *VV* is called the "venturi." The gasoline is admitted to *VV* through the spray nozzle *S*. The quantity of liquid flowing through *S* is regulated by the needle valve *NS*. When *N* is moved downward the supply is increased; when *N* is moved upward the supply is diminished.

The function of the carburetor is two-fold. First, its function is to supply a fine spray of gasoline into the venturi *VV*; second, its function is to regulate the supply of gasoline so

that the ratio by weight of gasoline to air is about 1 part of gasoline to 15 parts of air, this being approximately the right proportion for perfect combustion. Naturally the question arises here, How does air get into the carburetor, and how does the gas-air mixture get into the engine? When the piston head, Fig. 251 *II*, moves down a partial vacuum is created in the cylinder. If now the throttle *T*, Fig. 253, is open, air is sucked into *A* and a spray of gasoline flows from *S*, forming an explosive mixture in *VV*. This mixture is drawn into the engine by the initial downward stroke of the piston. On the following upward stroke the mixture is compressed, following which it is exploded by a spark from the spark plug in the cylinder head.

252. The Spark Plug. A spark plug, Fig. 254, consists essentially of a metal plug which fits into the cylinder head of the engine and which contains two carefully insulated wires, the points of which are close together. One of these wires runs up through the central insulating core *C* to the terminal binding post *T* at the top of the plug; the other wire is connected directly to the steel shell of the plug *S*, which screws into the piston head. Wires from a source of high electromotive force (battery or magneto and induction coil) are connected to the plug as follows: One wire from the battery system is connected directly to the terminal binding post *T*, Fig. 254; the other wire is connected to the metal case of the engine, the current being conducted to the plug wire through the metal shell *S*. It thus appears that while only one wire from the battery is visibly connected to the spark plug at the terminal *T*, the other connection from the battery is made through the metal parts of the engine.

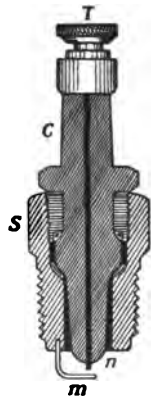


FIG. 254
Section of a
spark plug

When the electric circuit is closed through the mechanism

of the ignition system of the engine a spark occurs at the spark tips *mn*, thus exploding the mixture of air and gasoline in the cylinder. The essential parts of the ignition system of a gas engine consist of a battery or magneto (Art. 508), an induction coil (Art. 519), and a rotating device which is driven by the engine, and which is so designed as to open and close the electric circuit through the spark plug at the proper intervals.

253. The Steam Engine. The steam engine was first perfected by James Watt, a Scotch instrument maker. With reference to the nature of the principal driving parts, steam engines may be classified as (a) reciprocating, and (b) rotary. Again, as to the disposal of the exhaust steam, that is the steam which has been used in driving the moving parts, steam engines may be classified as (c) noncondensing, and (d) condensing engines. And, finally, with reference to the number of expansions performed by the steam, engines are (e) simple and (f) compound.



James Watt

The principle by which expanding steam is made to do work can very well be illustrated in an elementary way by means of a study of the simple, noncondensing, reciprocating engine. The operation of a simple reciprocating engine may easily be made clear by means of a laboratory model such as is shown in Fig. 255. Models of this sort showing clearly the working parts may now be obtained of dealers in physical apparatus for a few dollars. The working parts of a simple reciprocating engine is shown by means of line drawings in Fig. 256. Steam under high pressure is admitted to the cylinder *C*, first on one side and then on the other of the piston *P*, causing it to move back and forth from *a* to *b*. The admission of the steam to the cylinder

C is regulated by the sliding valve *S*, which permits live steam to escape on the other side. The motion of the valve *S* and

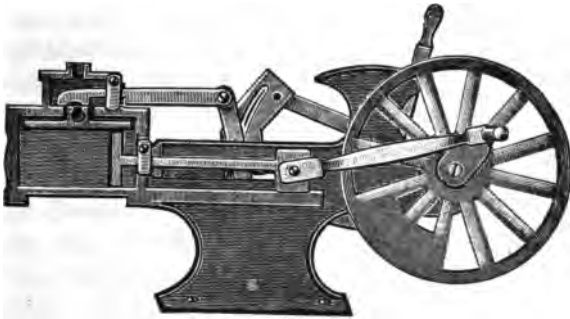


FIG. 255.—Demonstration model of steam engine

that of the piston *P* are in opposite directions. In *I*, Fig. 256, the piston is represented as moving to the right; in *II*, to the left.

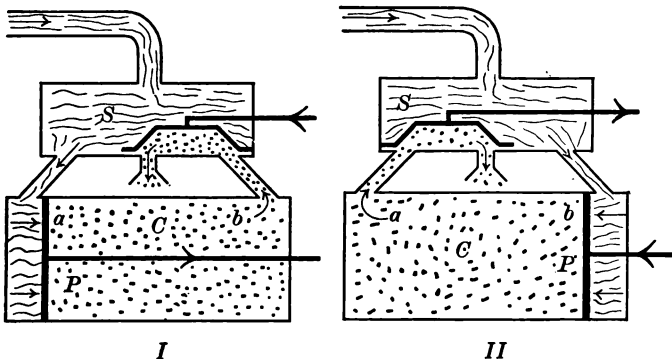


FIG. 256.—Sectional view of a reciprocating engine

The steam engine is a machine for transforming the potential energy of coal into the kinetic energy of mechanical motion. The two parts of the complete mechanism are the boiler, in

which the energy of the coal is transformed into the energy of steam under pressure, and the engine in which the energy of the steam is transformed into mechanical motion.

254. Other Types of Steam Engines. *Corliss engine.* The Corliss engine is a steam engine of the reciprocating type, in

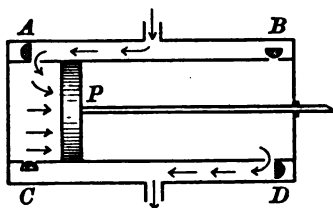


FIG. 257.—Sectional view of a Corliss engine

which the sliding valve of the simple engine shown in Fig. 256 is replaced by four rotating valves, Fig. 257, A, B, C, D, which are automatically opened and closed at the proper time by the engine itself. Valves A and B are for admitting the steam, and C and D, for letting

the steam out. When valve A is open to admit steam, valve D is also open to let steam out of the other end of the cylinder, while B and C are closed; on the reverse stroke B and C are open, while A and D are closed. Corliss engines are more efficient than reciprocating engines of the slide valve type, and are used extensively in large plants.

Condensing engine. Most of the heat brought to the engine by the steam from the boiler is ejected by the engine in the exhaust. This loss of heat varies from 70 per cent of the heat of the steam in the best engines, to over 90 per cent in the poorer types. In many manufacturing establishments the heat of this exhaust steam is recovered by using it for heating or manufacturing purposes. In some modern engines steam is superheated previous to its admission to the engine. This is to prevent its condensation on entering the expansion chamber. By means of the use of superheated steam the economy of a simple non-condensing engine may be made nearly equal to that of a compound condensing engine.

A *noncondensing engine* is one in which the exhaust steam passes directly from the cylinder to the atmosphere. In this case the piston always works against a back pressure of one

atmosphere; that is, there are two forces acting on the piston when it is in motion. One is the steam tending to drive it in one direction, and the other is atmospheric pressure tending to drive it in the opposite direction. It is clear, therefore, that if the atmospheric pressure could be removed the efficiency would be increased to the extent of 14.7 pounds per square inch. The *condensing engine* is one in which the exhaust steam passes into a cooling chamber. This usually consists of a chamber surrounded by water and into which a spray of cold water is admitted. When the steam comes in contact with the cold spray it is condensed, producing a partial vacuum, and thus reducing the back pressure on the piston.

Compound engine. A compound engine is one in which the steam under high pressure enters one cylinder, does work upon the piston, then enters a second cylinder, again doing work, and so on. When the steam exerts its pressure upon two cylinders in succession, the engine is called a double-expansion engine; when it acts upon three cylinders, a triple-expansion engine, etc. In some of our ocean going vessels, engines have been used of the triple-expansion type.

Figuring on the basis of economy and of steam pressure, it has been found that in the case of condensing engines the following rule applies: (a) For a steam pressure under 100 pounds per square inch, single cylinder condensing engine; (b) 100 to 150 pounds, double-expansion condensing engine; (c) above 150 pounds, triple-expansion condensing engine.

Steam turbine. The reciprocating engine is the familiar type, in which a piston moves back and forth in the cylinder. In the steam turbine, Fig. 258, steam under high pressure is driven against the blades of a wheel, thus causing rotation. In some types of the steam turbine the steam in passing through the rotating system strikes successively against two or more sets of blades in its passage from one end of the revolving drum to the other. At the end of the drum where the steam

enters, the blades are smaller than at the other end, the steam thus in moving forward expands, doing work at the expense of its own heat. Steam turbines have the advantage over reciprocating engines in that they occupy less space and run more quietly. They are used largely on steamships and in running electric generators.

255. Efficiency of Heat Engines. The efficiency of any piece of heat apparatus, whether it be a steam engine, a fur-

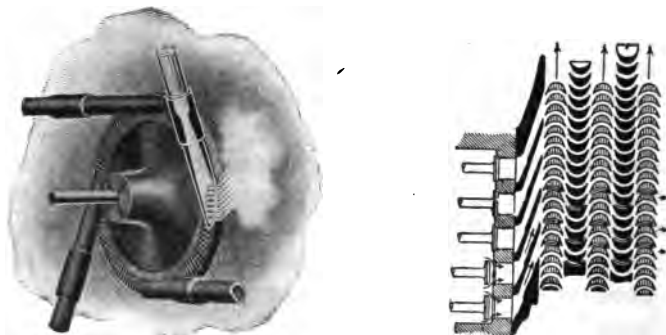


FIG. 258.—Steam turbine

nace, or an ordinary gas burner under a kettle, is the ratio of the useful energy gotten out to the total energy put in; that is,

$$\text{efficiency} = \frac{\text{useful energy out}}{\text{heat energy in}}$$

Example. One cubic foot of gas is burned under a kettle containing a gallon (8 pounds) of water. The temperature of the water is changed from 68° F to 110° F. Find the efficiency of the burner and kettle.

Solution: One cubic foot of gas gives 600 B.t.u. of heat. To change 8 pounds of water from 68° F to 110° F requires $8 \times 42 = 336$ B.t.u. Efficiency = useful energy out/heat energy in = $336/600 = 56$ per cent.

The efficiency of the ordinary locomotive is about 3 to 4 per cent, which means that for every hundred per cent of energy put into it in the form of coal we get in return only about 3 to 4 per cent in the form of useful work. The locomotive is an exceedingly wasteful device so far as fuel and energy are concerned. A glance at Fig. 259 in which there



FIG. 259.—In the ordinary railway locomotive only about 4 per cent of the energy in the coal is converted into useful work

is shown five engines, four pulling and one pushing, a train up a heavy western mountain grade, will explain in part why the efficiency of the ordinary locomotive is not over 4 per cent.

In engine efficiency tables the values are reckoned in terms of the engine, no account being taken of boiler and steampipe losses of energy. In the case of the steam engine the boiler furnishes to the engine only about 60 per cent of the energy of the coal. It is possible to compute from given data the coal-to-fly-wheel efficiency.

For example, in the case of a noncondensing stationary engine it was found that the engine efficiency was 8.7 per cent. This, however, represents only 60 per cent of the total energy. Therefore, an 8.7 per cent engine efficiency represents only 5.2 per cent efficiency with reference to the energy originally possessed by the coal.

In the gas engine the fuel is burned directly in the cylinder, thereby reducing radiation and other heat losses to a minimum. The efficiency of the gas engine, as measured by the number of B.t.u. per cubic foot of gas consumed, is high, 25 per cent or greater. It must be remembered in comparing engine efficiencies, however, that the fuel used by the gas engine is more expensive than that used by the steam engine.

REVIEW EXERCISES

1. Define: heat, temperature, thermometer, freezing point, boiling point.
2. Explain by means of a sketch the relation of the C scale to the F scale for the temperature range included between the freezing point and the boiling point.
3. Give the equivalent F readings for the following: (a) 70°C ; (b) 50°C ; (c) 25°C ; (d) -5°C ; (e) -2°C .
4. Give the equivalent C readings for the following: (a) 113°F ; (b) 77°F ; (c) 14°F ; (d) -13°F .
5. Find the boiling point and the freezing point of mercury (a) on the C scale; (b) F scale.
6. Find the boiling and freezing points of alcohol on (a) the C scale; (b) F scale.
7. Explain the distinction between temperature and quantity of heat.
8. Define: calorie, B.t.u., specific heat.
9. Explain how to find the specific heat of a body by the method of mixtures.
10. Explain each term in this equation: $m \times t \times s = m' \times t' \times s' = m'' \times t'' \times s''$. What is the relation between t' and t'' ?
11. How many calories of heat will be required to change the temperature of 100 grams of the following substances from 0°C to 100°C : (a) water? (b) iron? (c) lead?

12. One hundred grams of mercury at 100°C are stirred with 100 grams of water at 20°C and the resulting temperature is 22.5°C . What is the resulting temperature?

13. (a) Define coefficient of linear expansion. (b) How may the coefficient of cubical expansion for a given substance be derived from its coefficient of linear expansion?

14. Five hundred grams of copper, specific heat 0.09, temperature 120°C , are dropped into 500 grams of water at 20°C . What is the resulting temperature?

15. Give examples of the practical applications of the expansion of solids.

16. Discuss the expansion of water from 0°C to 8°C .

17. A brass rod at 0°C has a length of 200 cm; at 100°C its length is 200.36 cm. Find its coefficient of expansion.

18. The coefficient of expansion of nickel steel is 0.00001. A rod of this material having a length of 5 meters at 20°C will have what length in centimeters at 12°C ?

19. What is the coefficient of expansion of gases, and wherein does it differ from the coefficient of expansion of solids?

20. Define Absolute temperature, and explain how readings on the Absolute scale may be obtained from readings on the C scale.

21. The lowest temperature thus far obtained is said to be -273.3°C . What is this value on the Absolute scale?

22. State the law of (a) Charles; (b) Gay-Lussac.

23. Explain each term in the equation: $V : V' = T : T'$

24. A given mass of gas has a volume of 273 cm^3 at 0°C . Find its volume at (a) $+10^{\circ}\text{C}$; (b) -10°C , the pressure remaining constant.

25. A given mass of gas free to expand has a volume of 500 cm^3 at -13°C . What will be its volume at $+27^{\circ}\text{C}$, the pressure remaining constant?

26. A liter of gas at -3°C expands under constant pressure due to a change of temperature, to 1200 cm^3 . Find the change in temperature in C degrees.

27. State the principal facts relating to the fusion of crystalline solids.

28. Define heat of fusion, and explain what is meant by saying that the heat of fusion of ice is 80 calories.

29. How many calories of heat will be required to change 10 grams of ice at zero to water at 20°C ?

30. How many calories of heat will be required to change 10 grams of ice at -10°C to water at the boiling point, the specific heat of ice being 0.5?

31. State two ways by which the boiling point of water may be raised.

32. To what elevation in feet must water be taken above sea level in order that its boiling point be lowered to 90°C ?

33. State the principal facts relating to boiling, and explain their application to the boiling of water.

34. State and illustrate the principal facts which relate to evaporation.

35. Define heat of vaporization, and explain what is meant by saying that the heat of vaporization of water is 538 calories.

36. How much heat is required to change 100 grams of ice at 0°C to 100 grams of steam at 100°C ?

37. One kilogram of steam in a radiator at 100°C condenses to water, the temperature of which falls to 90°C . How many calories of heat are given out?

38. What is the distinction between vapor pressure and vapor tension?

39. Define: (a) humidity, (b) relative humidity.

40. On a certain winter's day, when the temperature was 41°F , outdoor air was found to contain 6.22 g of water vapor per m^3 . Express the relative humidity of this air in terms of per cent.

41. Air, as described in Problem 40, was heated and allowed to enter a living room at a temperature of 68°F , without the addition of moisture in the passage through the heating furnace. (a) Find the relative humidity of the air in the room after being heated. (b) How much is this humidity below that required for health and comfort?

42. (a) Define and give illustrations of conduction, convection, radiation. (b) Explain wherein radiation differs from conduction and convection.

43. Compare the relative conductivities of solids, liquids, and gases.

44. Give illustrations of practical applications of the non-conducting properties of certain substances, and explain in each case.

45. Discuss the radiating and absorbing power of lampblack as compared with that of a metal having a bright polished surface.

46. Give three methods of producing cold by artificial means, and give an example illustrating each.

47. Explain the ice cream freezer with reference to construction and refrigeration.

48. Name some of the fuels used in your community, and give their respective heats of combustion.

49. What are some of the advantages of a furnace (hot air, hot water, or steam system) over those of a stove for heating a residence?

50. Discuss the care and operation of a heating furnace, with reference to economy in the use of different fuels.

51. Name the chief constituents of the air and describe some of the most important properties of each.

52. Explain why buildings used for animal habitation (human or otherwise) should be ventilated.

53. Discuss several different methods of ventilation.

54. Explain Joule's experiment.

55. Define mechanical equivalent of heat, and give its value in (a) metric units; (b) English units.

56. The temperature of 10 grams of water is changed from 20°C to the boiling point. Find (a) the number of calories of heat required; (b) the equivalent value in ergs.

57. One quart of water (2 lbs.) is heated from the freezing point to 132°F (a) How many B.t.u. are required to effect this change of temperature? (b) The heat consumed by the water is equivalent to how many foot pounds?

58. One ton of hard coal of average grade is burned. (a) How many B.t.u. of heat are liberated? (b) How many cu. ft. of illuminating gas would be required to furnish the same quantity of heat?

59. Suppose that 10 tons of coal are required to heat a certain house for a year, the heating apparatus being a hot air furnace, the efficiency of which is 60 per cent. Find (a) the total number of B.t.u. liberated in the furnace; (b) the number of heat units delivered through the registers.

60. In one hour a 10-horse power engine burns 18 lb. of coal. (a) How much work in foot pounds is done by the engine during the hour? (b) The burning of 18 lb. of coal is equivalent to how many B.t.u.? (c) 18 lb. of coal is equivalent to how much energy in foot pounds? (d) What is the efficiency of the engine?

61. By means of a sketch explain the operation of a four-cycle gas engine.

62. By means of a sketch, explain the operation of the slide valve reciprocating steam engine.

CHAPTER VII

SOUND

THE NATURE OF SOUND

256. Introductory. Of the five great divisions of physics, namely, mechanics, heat, sound, light, and electricity, the subject of sound has until quite recently received less attention on the part of investigators than almost any other branch of the science. The reasons for this are manifold, two being especially noteworthy. First, the brilliant discoveries in recent times of the radio-active properties of matter, and the consequent stimulation of research in the related subjects of heat, light, and electricity, have claimed the attention of investigators in these fields; and in the second place, there is no doubt that for many years engineers and others interested directly and indirectly in the physical sciences have felt that while the subject of sound had an academic interest for the physicist and mathematician, it nevertheless was of little practical importance. Happily the day has gone by when we can say just what is and what is not of practical importance. Indeed events within very recent times have taught us that the word "practical" has a much wider application than was formerly dreamed of. Any investigation which widens the bounds of human knowledge, or which co-ordinates scientific data already tabulated may be of the utmost practical importance, as is evidenced, for example, by the application of the principle of photography to the solution of the extremely difficult problems associated with acoustics of large auditoriums.

And, too, there are other and quite different reasons why the subject of sound holds for us, or should hold for us, a most unusual interest. Human life differs in one important respect from other forms of animal life, and that is in its appreciation

and application of sound. The wants of the little child are manifested by sounds. Human intercourse is carried on mainly through the medium of sounds—spoken words. And the most aesthetic emotions are aroused by the production of periodic and co-ordinated sounds, as exemplified in music.

257. Origin of Sound. All sounds originate in vibrating bodies. If a continuous sound be traced to its source there will always be found a vibrating body. If a tuning fork be set in vibration and then brought in contact with a small glass or ivory ball, the ball will be thrown vigorously from the fork, due to the vibration of the latter. Again, if the prongs of the tuning fork be thrust into water the latter will be thrown about in a fine spray. Other illustrations of the fact that sound is generated in vibrating bodies may be seen in the vibration of a guitar string. If the string be plucked aside and released it will give forth a musical note, and at the same time it will appear to spread out into a broad band having a hazy outline, which diminishes to the original size of the string as the sound dies away.

It has been stated that all sounds originate in vibrating bodies. Now bodies may vibrate in a great many different ways; for example, the branches of a tree or the heads of grain in a field vibrate back and forth in the wind, each part in its motion to and fro traveling through the arc of a circle. A chip on the surface of deep water not only moves up and down, but back and forth as well, its motion being elliptical. Also if a ball attached to a rubber band in a vertical position be pulled downward and then released it will vibrate up and down in a straight line. A vibration somewhat similar to this occurs when a glass rod is stroked with a damp cloth. Grasp the rod in the middle with one hand and with a damp cloth in the other hand stroke the rod lightly, between the middle and the end. The glass rod will emit a distinct musical note, and at the same time a tremulous motion will be felt by the hand grasping it. Vibrations run from one end of

the rod to the other in a manner somewhat analogous to the up and down motion of the ball attached to the rubber band.

258. Wave Motion. When a disturbance occurs in an elastic medium, such as air or water, waves are set up. A



FIG. 260.—Water waves

wave motion represents a continuous handing on from particle to particle of a disturbance in a medium without an actual transfer of the medium itself. One of the most fa-

miliar examples of wave motion is that which occurs on the surface of water. Suppose that a stone be dropped into a lake or a pond, Fig. 260; the waves run out in concentric rings from the point of disturbance. To the observer it would appear that the water is actually being carried forward. This is not true, however, as may be seen by watching the motion of a chip floating upon the surface. As the waves move forward the motion of the particle upon the surface is up and down. Another excellent illustration of wave motion is seen in the passage of a wind wave over a field of grain. As the wave runs forward each individual head of grain swings back and forth.

The distinction between the motion of a particle of the medium and the motion of the wave itself is of fundamental importance. The bobbing up and down of the chip on the surface of the water and the swinging back and forth of the head of grain are both illustrations of the motion of the particle of the medium. In the case of the water the motion of the particle (the chip) is at *right angles* to the direction of the motion of the waves; in the case of the grain the motion

of the particle (head of grain) is back and forth in the *same general direction* as the motion of the wave.

259. Kinds of Wave Motion. There are two kinds of wave motion, transverse and longitudinal.

A *transverse wave* is one in which the vibrating particles move at right angles to the direction of the motion of the wave. A good illustration of transverse waves are those seen on the surface of water; also a series of waves traveling along a rope or string.

A *longitudinal wave* is one in which the vibrating particle moves back and forth in the *same direction* as the motion of the wave. Longitudinal waves may be illustrated by a row of balls suspended as shown in Fig. 261. If a disturbance be

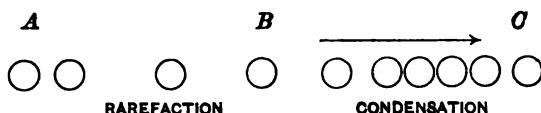


FIG. 261.—Rarefaction and condensation in a longitudinal wave

set up by striking ball A, it will be passed from ball to ball until the disturbance has run the length of the line. This illustrates a longitudinal wave, which consists of a condensation and rarefaction. As the wave runs forward from A to C there is a point where the particles are crowded together; this is called a *condensation*. At the point B the particles have begun to swing back toward A; this portion of the wave is called a *rarefaction*. A condensation and a rarefaction together constitute the entire wave.

Transverse and longitudinal vibrations may be shown experimentally by means of a metal rod clamped at the middle, as shown in Figs. 262 and 263. For example, if a steel rod clamped at the middle, Fig. 262, be plucked vertically at one end it will vibrate transversely; that is, the motion of the rod is at right angles to its length.

The same rod may also be made to transmit longitudinal waves. If it be stroked lightly about one-fourth the distance

from the end with a soft piece of leather upon which there has been dusted some powdered resin, the rod will give forth



FIG. 262.—Transverse vibration of a rod

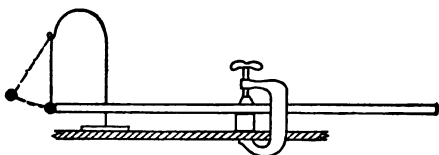


FIG. 263.—Longitudinal vibration in a rod

a distinct note of high pitch, and a small suspended ivory ball touching the rod lightly at one end will be thrown out vigorously, as shown in Fig. 263. Longitudinal waves consisting of condensations and rarefactions run the length of the rod from one end to the other

and back again, as shown by the motion of the ball.

Fluids (air and water, for example), are capable of transmitting only longitudinal waves within the medium, that is, waves consisting of condensations and rarefactions. Sound waves in air or in water, then, are transmitted by longitudinal waves, consisting of condensations and rarefactions. It should be noted here, however, that while a wave in water is an example of a longitudinal wave, a wave *on the surface* of the water is an example of a transverse wave.

260. Definitions. (a) The word *sound* is used in two distinct senses. From the viewpoint of the psychologist, sound is a sensation; from that of the physicist, sound is that form of vibratory motion which may be perceived by the ear. The question is often asked, If a tree were to fall and there were no ear to hear, would there be any sound? In the sense in which the word is used in psychology, there would be no sound; in the sense in which the word is used in physics, there would be sound, because the tree in falling would set up vibrations of the air which in turn would be capable of affecting the ear, if one were present.

(b) *Acoustics* is that branch of physics which treats of sound and its properties.

(c) *Wave length* is the distance measured in a straight line from any point in a given wave to the corresponding point in the next wave. In transverse waves we usually measure the wave length from crest to crest or from trough to trough, as from *a* to *b*, Fig. 264. In longitudinal waves we measure the wave length from condensation to condensation or from rarefaction to rarefaction. A wave length, however, is not necessarily measured from crest to crest or from condensation to condensation; it may be measured from any point in a wave to the corresponding point in the next wave.

Amplitude of vibration is one-half the distance through which a particle swings as the wave runs under it. In transverse waves the amplitude is measured at right angles

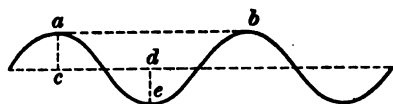


FIG. 264.—Wave length and amplitude

to the direction of propagation of the wave, *ac* and *de*, Fig. 264. In longitudinal waves, amplitude is measured in the same line as the direction of propagation of the wave. In the case of the swinging balls the amplitude of vibration is one-half of the space swept out by the swing (vibration) of any individual ball.

TRANSMISSION OF SOUND

261. Sound Waves Transmitted in All Directions. Just as the transverse surface water waves travel out in concentric circles in all directions over the surface from the point of disturbance, so in a somewhat similar manner sound waves in air travel outward in the form of condensations and rarefactions from the point of disturbance in a series of concentric spherical shells. Suppose, for example, a bell be struck. As it vibrates it sets up a series of condensations and rarefactions

which travel outward, as shown in Fig. 265. These waves striking upon the ear produce, due to the change of pressure caused by the condensations and rarefactions, a disturbance in the organs of hearing which give rise to the sensation of hearing.

Sound waves are not transmitted through a vacuum. This may be demonstrated as follows: Place an electric bell within a bell jar, as shown in Fig. 266. Connect the binding posts on the outside of the bell jar to the poles of a battery. When



FIG. 265
Condensations and rarefactions
of sound



FIG. 266
The ringing of the bell cannot
be heard in a vacuum

the electric circuit is closed the ringing of the bell can be distinctly heard. If now the air be exhausted from the bell jar, the sound of the bell becomes fainter and fainter, and finally dies away altogether.

The characteristics of a medium suitable for the transmission of sound waves are as follows: The medium must be *elastic*, *continuous*, and *ponderable*. When we say that a medium is ponderable, we mean that it has weight.

When energy from a given source is transmitted in all directions outward through a medium by means of waves (sound waves or light waves, for example), and we think of the waves as moving outward in all directions from the source,

we properly speak of the *speed* of transmission, since no definite direction is specified; when, on the other hand, we think of a given portion of a wave front as moving forward in a definite direction, we use the term *velocity*.

262. Velocity of Sound. The velocity of sound in any medium depends upon two factors: (a) the elasticity of the medium and (b) its density. The greater the coefficient of elasticity e of the medium, the greater the velocity; also, the greater the density d of the medium, the less the velocity. The relation of the velocity of sound to these two factors is expressed definitely by the equation

$$\text{velocity} = \sqrt{\text{coefficient of elasticity} / \text{density}}$$

$$v = \sqrt{\frac{e}{d}}$$

Example. If the velocity of sound in a given medium under given conditions of elasticity and density be 1000 feet per second, how will the velocity be affected if the coefficient of elasticity be increased fourfold and the density be increased from 1 to 16?

Solution:

$$1000 : x = \sqrt{1/1} : \sqrt{4/16}. \quad \text{Hence } x = 500 \text{ feet per second.}$$

263. Velocity of Sound in Different Media. The velocity of sound in air was first determined by two observers who stationed themselves several miles apart. A cannon was fired by one observer and the other noted the flash and counted the number of seconds required for the sound to reach him, it being assumed that the time required for the light to travel from the cannon to the observer was so small as to be negligible. In this way a calculation of the velocity of sound in air was made. Many later experiments have been devised and carried out to determine accurately the velocity of sound in different media.

The velocity of sound in air at 0° C is 1090 feet per second, or 332 meters per second.

The velocity of sound in water at 4° C is 4674 feet per second; that is the velocity in water is about 4 times that in air.

The velocity of sound in steel is 16,500 feet per second, or about 14 times that of sound in air.

The reason the velocity of sound in liquids and solids is greater than in air is due to the fact that the coefficient of elasticity of liquids and of solids is many times greater than that of air.

264. Relation of Temperature to Velocity. An increase in temperature causes an increase in the velocity of sound in air. The reason for this will be made clear when we consider the equation $v = \sqrt{e/d}$. When air, which is free to expand, is heated, its elastic properties remain unchanged, while its density is diminished, and thereby the value of v is increased. On the other hand, if the air be confined in a vessel of approximately constant volume and heated, the air cannot expand, hence there will be no change in its density; the coefficient of elasticity, however, will be increased, and as a result the value of v will again be increased. Thus we see that a change in temperature causes an increase in the velocity of sound in air.

A change in temperature of 1° C above or below 0° C causes a corresponding change in velocity of about 2 feet per second, or 0.6 meter per second.

EXERCISE. 1. Find the velocity of sound in air in feet and meters per second when the temperature of the air is (a) +20° C; (b) -20° C.

265. Reflection of Sound. When sound waves strike against an obstructing medium, such as the face of a cliff, the wall of a building, the trees of a forest, or even against the vapors of a cloud, they are reflected; that is, they bound off, as does a ball when thrown against a wall. Sound waves reflected from a smooth concave surface may be brought

to a focus by a similar concave surface as shown in Fig. 267. The ticking of a watch placed at *a* may be distinctly heard at *b*, although it may be entirely inaudible at *c*, midway between the two.

Sound may be reflected from a layer of air having a different density from that in which the sound wave is traveling. For example, a flame or the heated air rising from it

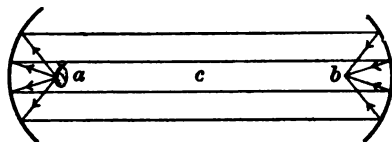


FIG. 267.—Reflection of sound

makes a fairly good reflecting surface. Also, warm air rising from the earth, due to the heat of the sun, may reflect sound. This explains why given sounds sometimes do not appear to be as intense during the daytime as at night. In the daytime, even when air is still and clear, sound waves traveling from a given source may encounter reflecting layers of air due to the fact of differences of temperature; at night, on the other hand, the air is of a more uniform temperature, and there is therefore less reflection and consequently less loss of energy. Travelers relate that in the long quiet nights of the polar regions sound may be heard for incredible distances.

266. The Echo. If a person call at a distance from a reflecting medium, in a very short time his voice will be returned to him in an echo. The *echo* is due to the fact that the sound waves traveling outward strike against the medium and are reflected back to the source. The echo is never as loud as the original sound, because a portion of the energy of the wave is always lost by absorption at the reflecting surface and a small portion is also lost as heat in traveling from the person to the reflecting medium and back again. Since the sensation of sound lasts for about one-tenth of a second; it follows that in order to hear an echo of one's voice it is necessary to stand far enough away from the reflected surface so that more than one-tenth of a second will elapse

between the origin of the sound and its return. Since at ordinary temperature (20°C) sound travels at the rate of about 1100 feet per second, it will therefore be necessary to stand at a distance greater than 55 feet from the reflecting surface in order to hear the echo.

Echoes may sometimes be heard when there is apparently no reflecting surface present. For example, the sound of a whistle or that due to the firing of a gun on the water is often heard to roll away (echo and re-echo) apparently to a great distance. The explanation of this phenomenon lies in the fact that the air, which is optically transparent, is acoustically opaque. The rolling sound which results from a series of echoes is due to reflections from layers of air which are very nearly acoustically impenetrable, and which therefore act as reflecting surfaces.



FIG. 268
The marimeter

267. Measuring Depths of the Ocean by Echoes.

One would naturally think that putting so intangible a thing as an echo to work would be an impossibility, yet a new and practical use of the echo has been found for making rapid and accurate soundings at sea. When a ship is approaching shore or otherwise is in relatively shallow water, it is of great importance that accurate information be obtained at frequent intervals of the depth of the water. In the past it has been the practice to "heave the lead," that is, to take soundings by means of a lead weight attached to a line. The new device for determining sea depths by means of echoes is called a "marimeter." The application of the principle involved in the case of this instrument will in all probability cause the ancient practice of heaving the lead to become obsolete.

It is known that sound travels in salt water at the approximate uniform speed of about 4000 feet per second. All that is needed then to measure the depth of the ocean at points near shore or in relatively shoal water is an instrument that will measure automatically the time required for a sound wave to travel to the bottom and to be reflected back as an echo. The *marimeter*, Fig. 268, does this very thing. A sound wave is sent out mechanically from

the bottom of the vessel and the instant this sound is started it is picked up electrically and relayed to the recording instrument, and the dial of the latter begins to register. The sound wave travels to the bottom of the ocean and returns in the form of an echo, and the echo is picked up by the diaphragm in the bottom of the boat. It is then relayed by electricity to the recording instrument, causing the pointer immediately to stop. The depth is recorded on the dial of the instrument in fathoms. By means of the marimeter four soundings per minute may be taken, whereas from 10 to 20 minutes for a single sounding were required by the old method.

268. Reverberations. The confused resultant sound which comes from the prolongation of a series of sounds resulting from reflections is called a *reverberation*. A reverberation is different from an echo in that in the case of an echo the original sound and the reflected sound (the echo) constitute two distinct impressions; a reverberation, on the other hand, is a prolonged confusion of sounds resulting from repeated reflections. For ordinary room temperature, an echo requires that the reflecting surface (wall or ceiling) shall be at least 55 feet from the source. Reverberations may arise, and indeed usually do arise, from reflections from surfaces which are much less than 55 feet from the source, as is illustrated by the confused sounds resulting from reflections which sometimes occur in auditoriums. A striking example of reverberation is that which occurs in the Baptistery of Pisa, a building circular in form and having a hemispherical roof. The effect, so far as the reverberations are concerned, is made more conspicuous by the good reflecting surface furnished by the polished marble with which the interior of the building is constructed. A single sound originating in the body of this building continues to be audible as a reverberation for 12 to 15 seconds.

A scientific study of the relation of reverberations to the acoustical properties of auditoriums has, within the past few years, led to important discoveries in the domain of architectural acoustics.

269. Architectural Acoustics. Until quite recent times the science of acoustics as applied to buildings received but scant attention. Not only was this phase of acoustics supposed to involve insurmountable difficulties but the whole subject was invested with an atmosphere of uncertainty and mystery. Many erroneous theories were in vogue and accepted almost without question. As an instance, it was commonly supposed that strings or wires stretched across an auditorium having bad acoustical properties would remedy the defects. We now know, however, that such devices are useless. And, further, it was currently reported that two buildings which are exactly alike may have acoustical properties which are quite unlike. This theory, however, turned out to be only

half true, based as it was on comparisons of buildings which were only apparently alike, but which in reality differed very materially in important details especially as relating to the materials which entered into the construction of the interior of the building and the furnishings. We now know that there is no reason why two auditoriums which are alike in all particulars should not have practically the same acoustical properties. In order that an auditorium may possess satisfactory acoustical properties it is necessary (a) that the sound reaching each individual member of the audience shall be sufficiently loud; (b) that the simultaneous components of a complex sound shall maintain their proper relative intensities; and (c) that the successive sounds in rapidly shifting articulation, as in speaking or in the production of music, shall be clear and distinct. These, says Professor W. C. Sabine, to whom much of our modern scientific knowledge of practical acoustics is due, are the necessary conditions for good hearing. The architectural problem of acoustics is therefore one which largely involves the factor of the confusion of sounds arising due to reverberations. It is true that there are other factors which might properly be taken into account in an advanced study of acoustics; in this text, however, we shall confine our attention to those which make for confusion.

270. Confusion of Sounds in an Auditorium. The factors to be considered under this head are those which are due to echoes and reverberations, and such extraneous sounds as may arise from street traffic, the snapping and pounding of steam pipes, and the noise sometimes caused by ventilating fans.

Echoes are sounds which are distinct from the original sound and which are, in general, due to normal reflection from acoustically plane surfaces. Echoes may occur in large buildings. The acoustic defects arising from echoes may quite easily be remedied by altering the reflecting surfaces.

Reverberations, on the other hand, give rise to a confusion of sounds which may prove very serious. A *reverberation* is a prolongation of the sound in all parts of the auditorium, and is due to a series of reflections resulting in a confused mass of sound. Reverberation is always a drawback so far as speaking is concerned; it cannot be entirely eliminated, however, without seriously reducing the factor of loudness to an undesirable extent.

While reverberation is a hindrance to good speaking, the presence of a certain amount of reverberation is necessary for the production of good music. It appears then that a hall which is acoustically good for speaking may, to a certain extent at least, be bad for the best musical effects, and vice versa.

The problem of correcting reverberation defects is a very important one, both with reference to the method of elimination and also with reference to the degree of elimination. A room in which there is too much reverberation is acoustically bad because of the resulting confusion of sounds; and on the other hand, a room in which there is too little reverberation may, musically speaking, be too "dead" to give satisfactory results.

271. The Period of Decay of a Reverberation. The time required for a reverberation to die away after the cessation of the original sound is called *period of decay*, or the *duration of the reverberation*, and is represented by the letter T . For a given note the value of T depends primarily upon the absorbing power of the interior of the auditorium.

In a hall acoustically good for public speaking the value of T should lie between 0.5 and 1 second. In a hall suitable for the best musical effects, however, T should be about 2.3 seconds. A room in which the period of decay (T) is as small as 2 seconds or as great as 3 seconds is not the most satisfactory for orchestral music.

272. The Remedy for Reverberation Defects. Reverberation is due to reflection; its remedy therefore lies in modifying the reflecting surfaces. Reverberation may, in general, be decreased by covering a part or parts of the walls with some soft material which possesses good absorbing and poor reflecting properties. Since sound at ordinary room temperature travels with a velocity of about 1100 feet per second it is usually not a matter of great importance on what wall or on what part of a wall the absorbing material is placed. The distance which sound travels in a second is so great compared with the dimensions of the ordinary hall that the sound waves are in general reflected many times in a second, and a relatively large amount therefore falls upon each unit of area of reflecting surface of the absorbing material, no matter where it is placed within the room. Nevertheless, in some halls a special study has to be made as to the best disposition of the accessory reflecting and absorbing material.

By a special process it is now possible to photograph sound waves. Some very beautiful photographs of this sort have been obtained by Professor Sabine and applied by him to the practical problem of auditorium acoustics. Two such photographs are shown in Figs. 269 and 270, in which a vertical section of a theater auditorium is represented. In Fig. 269 a sound wave (heavy curved line) is shown 0.05 second after the sound was produced on the stage at S . In Fig. 270 there is shown the position of the reflected waves 0.14 second after the production of the sound. The large number of reflected waves which seem to come from many directions were generated by the original impulse at S . These multiple waves continue to develop with increasing confusion, until the

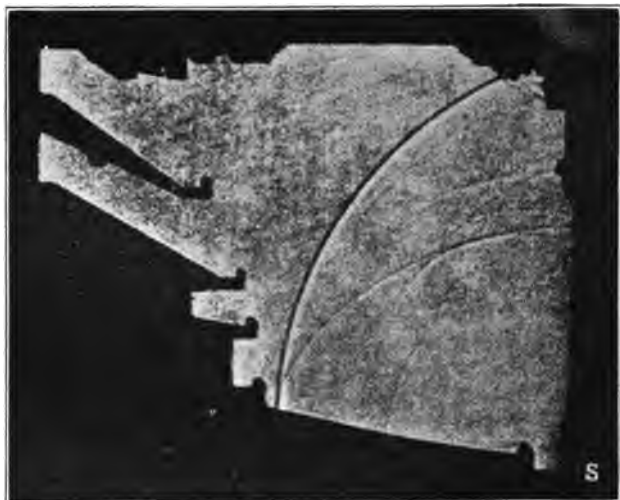


FIG. 269.—Position of a sound wave in an auditorium 0.05 second after leaving the origin at *S*

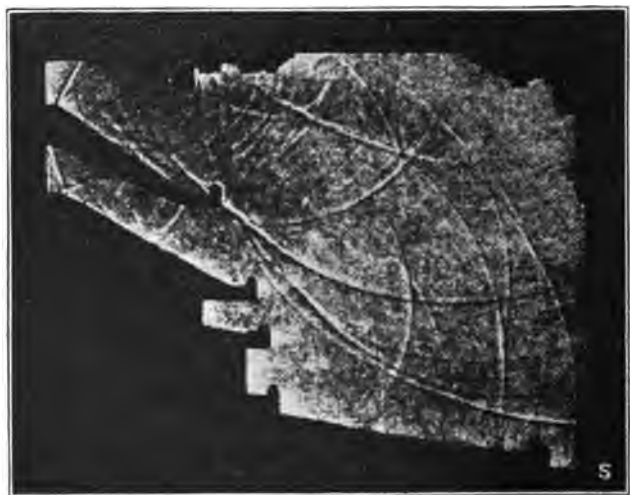


FIG. 270.—Reflected sound waves 0.14 second after the production of the original sound at *S*

sound is diffused throughout the entire auditorium, producing the condition called reverberation.

273. Coefficient of Absorption. An open window may be regarded as a perfect absorber, since all the sound falling upon it passes out. Sabine found by experiment what area of any particular material would cause the same absorption of sound as one square meter of open window. The *coefficient of absorption* of a given substance is the ratio of one square meter of open window to that area of the substance which is required to produce the same period of decay of reverberation. Thus, it was found that about 40 square meters of brick wall were required to produce the same period of decay as is produced by one square meter of open window. The coefficient of absorption of brick wall is therefore, $1/40 = 0.025$. The symbol for coefficient of absorption is p .

TABLE XXI

COEFFICIENTS OF ABSORPTION

Substance	p
Open window.....	1.00
Hair felt.....	.78
Audience per person.....	.44
Upholstered chairs.....	.30
Shelia curtains.....	.23
Carpet rugs.....	.20
Wood.....	.061
Plaster on lath.....	.034
Window glass.....	.027
Plaster on tile.....	.025
Brick wall.....	.025

274. Absorbing Power of a Hall. The *absorbing power*, a , of a given area is the product of the area in question times its coefficient of absorption. Since the interior of every hall is made up of various substances, to get the *total* absorbing power we shall have to multiply the area of each substance by its coefficient of absorption and then get the sum of the products thus obtained; that is,

$$\text{total absorbing power} = a = A_1p_1 + A_2p_2 + A_3p_3 + \dots$$

Thus if we have 100 m² of brick wall, 40 m² of window glass, and 20 m² of hair felt, the total absorbing power (see Table XXI) of the three areas is

$$a = (100 \times 0.025) + (40 \times 0.027) + (20 \times 0.78) = 19.18$$

To get the total absorbing power of an audience we multiply the number of persons present by the coefficient 0.44.

275. Sabine's Formula. Sabine found that the period of decay of reverberation may be expressed mathematically by the formula

$$T = 0.164 \frac{V}{a}$$

in which T is the period of decay in seconds, V is the volume of the auditorium in cubic meters, and a is the total absorbing power.

Sabine's equation may be employed in calculating the period of decay of reverberation for any auditorium, and thus the suitability of the building for music or speaking may be determined.

It has been found that for a building of given volume V , the shape of the auditorium has, to the first approximation at least, no effect on the value of T .

Example. The volume of the auditorium of the New Music Hall, Boston, is said to be 16,200 cubic meters. The absorbing areas, expressed in square meters, are: Plaster on lath, 1040; plaster on tile, 1830; window glass, 22. A full audience, including the orchestra, is 2660 persons. Find (a) the total absorbing power of the hall when a full audience is assembled; (b) the duration (T) of reverberation. *Solution:* (a) *The total absorbing power, a , is* $(1040 \times 0.034) + (1830 \times 0.025) + (22 \times 0.027) + (2660 \times 0.44) = 1252$; (b) $T = 0.164 (16,200/1252) = 2.12$ seconds.

276. Refraction of Sound. Sound waves may be refracted. *Refraction* is the change of direction of the motion of a wave

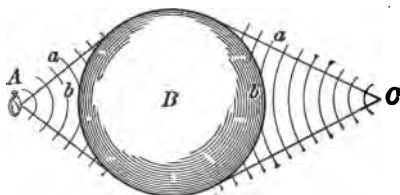


FIG. 271.—Refraction of sound waves

due to its passage from a medium of one density to a medium of different density. For example, if a series of sound waves originating at the point A , Fig. 271, strike against the balloon shaped body B , containing carbon dioxide, which is more dense than air, the waves will be bent in such a way that the sound will come to a focus at C . This may be readily understood when we consider what happens to the portion of the wave marked ab . Since b gets into the

dense medium first, its speed is retarded and hence the line of direction is bent downward as shown; *a* gets out of the medium first, and hence travels with a greater speed than *b*, thus bending the wave further towards *C*. Of course when both portions of the wave get into the air they travel with the same speed. If the balloon shaped vessel were filled with a gas lighter than air, such as hydrogen, the waves, instead of converging and coming to a focus as shown, would diverge.

In the passage through successive layers of air having different densities, sound waves may rise in one region and descend in another, thus producing "islands of silence." This condition is very well illustrated in Fig. 272 in which a sound wave starting at *A* rises in the region *B* and descends again at *C*. In the

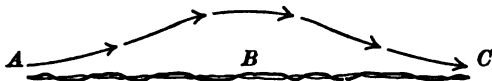


FIG. 272.—Sound heard distinctly at *A* and *C*; silence at *B*

regions *A* and *C* the sound may be heard distinctly, while at *B* there is a region of comparative silence. This phenomenon was discovered by Joseph Henry in 1860, who was at that time employed by the Government Light House Bureau. Henry noted that the sound of a steam siren at *A* often passed completely above a vessel at *B* but could be heard distinctly at a second vessel stationed at *C*. Refraction of this sort is caused apparently by successive layers of air having different densities, due to differences in temperature.

LOUDNESS AND INTENSITY OF SOUND

277. Distinction between Loudness and Intensity. *Loudness* is a term used to designate the strength of the sensation received through the medium of the ear. The loudness with which a given sound is heard depends in part on the energy of the vibrating system and in part on the nature of the hearing mechanism of the individual. It is probable that no two

persons hear the same sound with exactly the same degree of loudness; indeed, the loudness with which a given individual perceives a sound varies from time to time, depending upon the state of health and nervous condition.

Intensity of sound is a physical characteristic quite independent of the hearing mechanism. *Intensity* may be defined as the quantity of energy in the sound wave passing through a surface of unit area (1 cm^2) in one second. It is understood that the unit area is at right angles to the direction of propagation of the sound wave. Intensity, being a physical quantity, can be measured. Loudness, on the other hand, cannot be measured in physical units. Loudness is not a physical quantity; it is a sensation. We may say, however, that within certain limits *loudness is proportional to intensity*.

Intensity of sound depends upon several factors as follows: (a) distance from its origin; (b) amplitude of vibration; (c) frequency of vibration; (d) density of the medium; (e) area of the vibrating body.

278. Relation of Intensity to Distance. It is a common experience that if we walk away from a sounding body the loudness of the sound decreases as the distance increases. Now if the medium be of such a nature that the sound waves move out from the source in a spherical form, and also that there is little loss of energy due to friction between the particles of the medium, it may be shown both experimentally and mathematically that the *intensity varies inversely as the square of the distance from the source*. That is, at a point one mile from the source a person would hear the sound with a given loudness, while at another point two miles from the source the same person would hear the sound only one fourth as loud.

It should be noted however, that this exact relationship between intensity and the square of the distance holds strictly only in case of waves spreading in a spherical form. Owing to the presence of reflecting surfaces, sound waves produced

under ordinary circumstances do not remain spherical and consequently the inverse square law does not apply exactly to sound waves produced on the surface of the earth. Also, in the case of sound waves traveling in a tube (as for example, a speaking tube) the energy is transmitted from layer to layer of equal areas without much loss due to the spreading of the wave, and consequently sound will travel in a confined space such as a tube to a relatively great distance without much diminution in intensity. This fact explains the efficiency of the speaking tube and the megaphone.

279. Relation of Intensity to Amplitude of Vibration. If, for example, the prongs of a tuning fork be tapped lightly so that they vibrate through a very small arc, a faint sound is heard; if now they be struck sharply, so that the prongs vibrate through a very much larger arc, they give rise to a sound much louder than the first. It can be shown that in the case of simple vibratory motions the *intensity of the sound varies directly as the square of the amplitude of the vibrating medium*. If a vibrating body having an amplitude of one unit produce a sound of given intensity, and if then the body be made to vibrate through an amplitude of 2 units, the intensity will be 4 times as great.

280. Relation of Intensity to Frequency. It may also be shown that for simple vibratory motions the *intensity is directly proportional to the square of the frequency*, that is, to the square of the number of vibrations per second. Thus if a sound wave of given amplitude in a given medium have a frequency of 100 vibrations per second it will produce a sensation of a certain intensity. Now if this wave be made to vibrate twice as fast, the amplitude remaining constant, the intensity will be 4 times as great as before.

If both amplitude and frequency be doubled the loudness will be increased as the product of the square of these factors; in other words the intensity will be $2^2 \times 2^2 = 16$ times as great as in the first case.

281. Intensity Affected by the Density of the Medium and by the Area of the Sounding Body. As one ascends in a balloon the air becomes rarer and rarer as the distance from the earth increases, and it has been observed that the loudness of the sound diminishes. If, on the other hand, a person goes down into a deep mine or down in a diving bell, the sound of the human voice will be much louder than at the surface of the earth. We may therefore conclude that for air the rarer the medium the less loud is the sound, and the denser the medium the louder is the sound.

Also, the loudness of sound is affected by the area of the sounding body. This may be shown by the following simple experiment: If a tuning fork be set in vibration and held in the hand, a sound of a given loudness will be heard. Now if the base of the tuning fork, while still in vibration, be placed in contact with the top of the desk or upon a resonance box, the sound will at once become very much louder, due to the fact that a body of increased area is set in vibration.

EXERCISES. 2. A given sound originates at a point in air under such conditions that simple sound waves travel outward from the source in spherical form. The sound at 100 feet from the source has a given intensity. What is the relative intensity at a point 300 feet from the source?

3. Suppose that the frequency of the sound wave be doubled and the amplitude be made three times as great, how will the intensity at a given point be affected?

RESONANCE AND INTERFERENCE

282. Free and Forced Vibrations. The vibration of a pendulum free from all influences, except that due to the attraction of gravity, is an example of a *free vibration*. If there were no friction, the pendulum would continue to vibrate forever. As it is, however, all freely vibrating bodies sooner or later come to rest, due to the damping effect of the friction of the medium in which they swing. Examples of free vibrations are seen in the motion of the pendulum, as described

above, also in the motion of a guitar string, or in that of a tuning fork.

When a body vibrates not in response to its own nature but in response to some periodic force applied to it, we have what is called a *forced vibration*. A good illustration of a forced vibration is that of the motion of the pendulum of a clock or the balance wheel of a watch, in which case the vibrating bodies move in response to a periodic force applied by the weights or spring. Other examples of forced vibrations are those of the sounding board of a piano, or the body of a violin, or the case of the desk when the stem of the tuning fork is pressed upon it.

283. Resonance. When the period of the vibrating body is the same as that of the impressed force we have a special case of forced vibration known as *resonance*. If, for example, two tuning forks of the same period be mounted near to each other, and one set in vibration and after a few moments stopped, it may be observed that the other fork is vibrating, as may be demonstrated by a light ivory ball suspended so as just to touch the fork. This is due to the fact that the impulses of the air from the first fork act upon the second, and since its period of vibration is the same as that of the impulses impressed upon it, it responds. A further illustration of the relation of the impressed force to the period of the vibrating system is seen in the case of the swing. A little child may set a heavy swing in vibration, provided the impulses (pushes) be so timed as to coincide with the period of vibration of the swing. First the swing moves through a very small arc, but soon it responds to the periodic impulses, and may after a time swing through a large arc. The motion of the swing is an example of a forced vibration, and since its period of vibration coincides with the impulses imparted by the child, we have a case of resonance.

A striking illustration of resonance is that of the vibration of a light bridge, due to the footfalls of soldiers stepping in

unison, Fig. 273. If the period of the impulses imparted by the soldiers agree with the period of the bridge, the latter will be set in vibration. Soldiers when crossing a bridge are

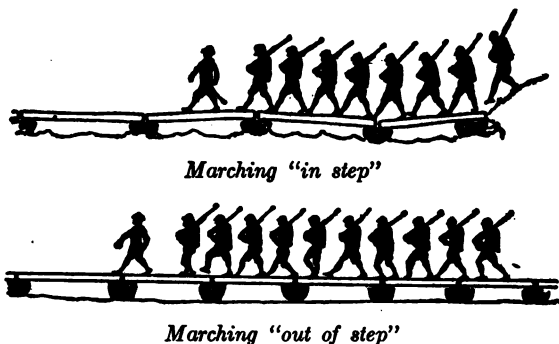


FIG. 273.—Resonance illustrated by soldiers marching across a light bridge therefore usually commanded to break step to avoid the possibility of doing damage to the structure, due to the resonance in response to the regular foot falls.

284. Resonators. A tube so adjusted that the air within it vibrates in unison with some outside vibrating body, such as a tuning fork, is called a resonator. If a glass tube, Fig. 274 A, be partly immersed in water and moved up and down while a fork vibrates above it, there will be found a certain point at which the tube will respond to the fork, that is, the resonance tube will give out a relatively loud sound. Now if a fork having a different vibration rate be held above the tube, no response is heard. If, however, the tube be moved up or down, there will be found another point at which it will respond to the second fork. Thus each fork requires a tube of a certain length to be in resonance with it. This illustrates resonance in the case of a tube closed at one end, as by the water. Resonance for a given fork may also be obtained from a tube open at both ends, provided the tube be twice the length of the closed tube, Fig. 274 B.

285. Explanation of Resonance in a Tube. Let a , b , c represent the motion of one prong of a tuning fork which is vibrating at the mouth of a closed resonance tube, so adjusted as to respond to the fork.

As the prong of the fork moves from a to b a condensation is sent down into the tube. While the fork moves from b to c and comes to rest for a moment in changing its direction of motion, the condensation has time to run down the tube, strike the water, be reflected, and get back to c in time to join the new condensation which is formed as the fork moves from c toward b . The condensations and rarefactions which are reflected from the bottom of the tube coincide with the condensations and rarefactions of the sound waves given off by the fork, thus producing a re-enforcement of the sound, and hence giving rise to an increase in loudness.

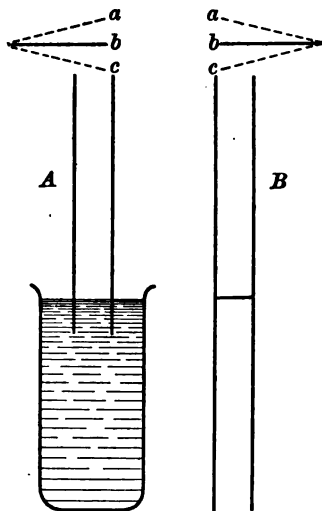


FIG. 274.—Closed and open resonance tubes

286. Relation of the Length of a Wave to Length of Resonance Tube. Let us consider again the case of a resonance tube which is closed at one end and which is responding to a given fork. A sound wave travels one wave length while the fork makes one complete vibration. Now we have learned that during one complete vibration of the fork a condensation travels twice the length of the tube (down and back), and a rarefaction likewise travels twice the length of the tube. A sound wave consists of a condensation and rarefaction each of which, during one complete vibration of the fork, travels twice the length of the resonance tube. It follows, therefore,

that a *closed resonance tube* sounding its lowest note is *one-fourth* the wave length of the corresponding sound wave in air.

It may be shown in a somewhat similar manner that an *open resonance tube* sounding its lowest note is *one-half* the wave length of the corresponding wave length in air.

287. Relation of Wave Length to Velocity and Number of Vibrations. Suppose that the fork is making 256 vibrations per second and we desire to find the wave length of the corresponding sound waves in air when the temperature is 20° C. Now the velocity of sound at 20° C is 1130 feet per second. While the fork is making 256 vibrations sound travels a distance of 1130 feet. This means that in a space of 1130 feet there are 256 waves. Therefore, the length of one wave = $\frac{1130}{256} = 4.4$ feet. It follows then that the length of a wave in an elastic medium may be represented by the equation

$$\text{wave length} = \frac{\text{velocity}}{\text{frequency}}$$

$$l = \frac{v}{n}$$

in which l is the wave length, v the velocity of the sound in air, and n the frequency, that is, the number of vibrations per second.

288. How to Measure Wave Length and Number of Vibrations by Means of a Resonance Tube. It is possible by means of a resonance tube to measure with a reasonable degree of accuracy the wave length of the sound given off by a tuning fork, and also to determine the number of vibrations per second, that is, its frequency. Suppose that we wish to determine the wave length and the number of vibrations per second of a given tuning fork. A glass tube one end of which is thrust into water, as already explained, serves as a resonance tube. The given fork is set in vibration and held above the

tube, which is moved up and down until the point of resonance is reached. We now measure the distance from the fork to the water, which represents the length of the closed resonance tube. Four times this length equals the wave length of the corresponding sound in air.

Now by means of the relation, $l = v/n$, we may at once determine n , the number of vibrations per second. Suppose the temperature at which the experiment is carried out is 26°C and that the length of the resonance tube is 10.5 inches. At a temperature of 26°C the velocity of sound, v , in air = $1090 + (2 \times 26) = 1142$ feet per second; and wave length $l = 4 \times 10.5$ inches = 42 inches = 3.5 feet. Now using the equation above, we may write

$$n = \frac{1142}{3.5} = 326 \text{ vibrations per second}$$

Example. A closed resonance tube 18 inches in length responds to a given fork which makes 188.5 vibrations per second. Find the temperature at the time when the experiment was performed. *Solution:* Wave length $l = 4 \times 1.5 = 6$ feet; frequency $n = 188.5$; velocity of sound $v = 1090 + (2 \times t)$. Then from the equation $l = v/n$ we find that $t = 20.5^{\circ}\text{C}$.

EXERCISES. 4. A closed resonance tube 1 ft. in length responds to a fork making 288 vibrations per second. Find (a) the velocity of sound corresponding to the conditions of the experiment; (b) the temperature.

5. Find the length of a closed pipe that will respond to a fork making 256 vibrations when the temperature is 10°C .

6. Determine the frequency of a fork that is in resonance with a closed tube 15 in. in length at 0°C .

289. Re-enforcement and Interference of Sound. If two sound waves occur together so that the condensations and rarefactions of one coincide with the condensations and rarefactions of the other, the resulting sound will be louder than either of the sounds producing it. In Fig. 275 there is shown in a graphic way the result of adding two sound waves, as

has just been described. The resultant sound wave is represented by the line having an amplitude greater than either of the other waves.

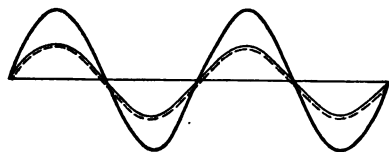


FIG. 275.—Re-enforcement of sound

On the other hand, if two sound waves be superimposed one upon the other, so that the condensation of one coincides with the rarefaction of the other, the result will be a diminution in loudness.

Indeed it is possible for two sound waves to be so impressed one upon the other that silence will result.

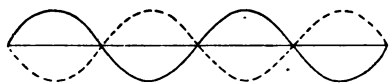


FIG. 276.—Interference of two sound waves resulting in silence

This condition is shown in Fig. 276, in which is represented graphically two sound waves of the same wave length and amplitude, the condensations of one

coinciding exactly with the rarefactions of the other. The resultant is represented by the straight line, which indicates silence.

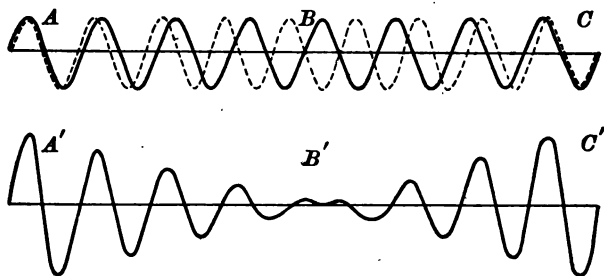


FIG. 277.—Interference of two sound waves producing beats

The amplitude of the resultant sound wave is at every point equal to the algebraic sum of the amplitudes of the original sound waves producing it.

290. Beats. Suppose that we have two sound waves of different lengths traveling in the same direction, as shown in Fig. 277. At the points *A* and *C* the waves coincide in such a way that they re-enforce each other. At *B* they interfere in such a way as partially to annul each other. The resultant wave is represented by the line *A'B'C'*. At the points *A'* and *C'* the sound will be loud; at the point *B'* it will be faint, thus producing a rise and fall in loudness. This periodic increase and decrease in loudness due to the interference of two sound waves is called *beats*.

A striking illustration of beats occurs in connection with the singing flame.

Let two jets of flame be prepared as shown in Fig. 278. First, over one of the

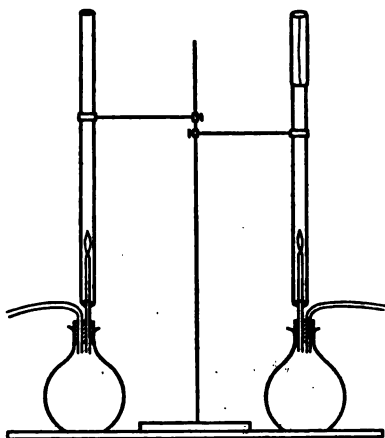


FIG. 278.—Production of beats by the singing flame

flames place a glass tube about 2 feet in length and from three-quarters to an inch in diameter. Move the tube up and down until a certain position is found in which the flame will sing, due to the sympathetic vibrations set up in the tube by the fluttering of the flame. Now over the second flame place a similar tube, having around one end a cylinder of paper which may be moved up or down as the case may require. The paper slider may be adjusted until the point is reached at which the second tube produces a singing noise. Now if the wave lengths given out by the two tubes be somewhat different, a very beautiful illustration of interference (beats) occurs. A distinct throbbing sound will be heard due to the interference of the two wave trains.

The *number of beats* which occur per second is equal to the difference in frequency of the two sounding bodies. For example, if two forks *A* and *B* are sounding together, the frequency of *A* being 256 and that of *B* 292, the number of beats occurring per second will be $292 - 256 = 36$.

PITCH AND MUSIC

291. Pitch. The *pitch* of a sound is that characteristic which is determined by its frequency. When the number of vibrations per second is great, the pitch is high; when the number of vibrations is small, the pitch is low. If two sounds are produced by the same number of vibrations per second they are said to have the same pitch, and if sounded together they are said to be in *unison*.

Pitch may be measured by means of a *siren*, which consists of a circular disc having several concentric rows of holes, and which is mounted so as to rotate on its central axis at a given speed, as shown in Fig. 279. If

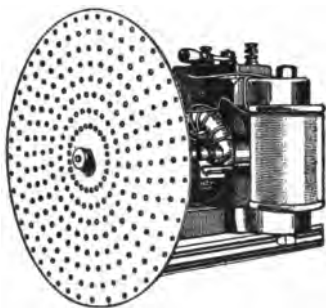


FIG. 279.—Siren, driven by an electric motor

a stream of air be blown through a tube against the rapidly rotating disc in line with a row of holes, a note of a definite pitch is produced. When one of the holes of the rotating disc comes in front of the tube a puff of air goes through, thus producing a condensation; at the next instant the air is cut off by the disc, producing something corresponding to a rarefaction. Now

if the disc be rotated at a given speed and the tube through which the air is blown be slowly moved from the center of the disc toward the circumference a series of sounds will be produced which increase in pitch from low to high notes, due to

the fact that the holes in the disc increase in number from the axis outward. To determine the pitch of a given note as produced by the siren we must know the number of holes in the particular series in front of the tube and also the number of the rotations of the disc per second. Suppose that in the outside row there are 48 holes and the disc is making 10 revolutions per second. This will give $10 \times 48 = 480$ condensations and rarefactions, that is, 480 vibrations per second. The resulting note is one having a pitch due to a frequency of 480.

If a siren be provided with an apparatus that will count automatically the number of revolutions per second, it is possible by means of this instrument to determine the number of vibrations per second of a given sound, provided the operator is able to tell by ear when the two sounds, that of the siren and that of the given body, are in unison. Suppose that we wish to determine the number of vibrations per second made by the wings of a bee buzzing on the window pane. The speed of rotation of the siren is gradually increased until the pitch of the instrument coincides with that of the wings of the insect. At this instant the number of revolutions per second is noted, which multiplied into the number of holes passing before the tube gives the number of vibrations required. In a similar manner the frequency of any instrument, such as a tuning fork, may be determined.

292. Musical Sounds. A *musical sound* is one which has a definite pitch and which produces an agreeable effect upon the ear.

A noise is a combination of sounds in which the ear is unable to detect a definite pitch, as in the confused sounds resulting from street traffic or in the clatter of machinery in a factory. Relatively speaking, noises are sounds which produce disagreeable or irritating effects on the hearer. According to this way of putting it, then, it follows that what may be classified as a noise by one person or people may be considered

as music by another. A notable case in point is that furnished by Wagner's "Tannhauser Overture." Soon after the appearance of this famous overture a German critic of Frankfort likened it to a display of "shrill noises and broken crockery effects."

The essential characteristics of musical sounds are (a) definiteness of pitch, (b) periodicity, and (c) agreeableness to the ear. A series of sounds may have a definite pitch and may be periodic and yet not be pleasing to the ear, as in the case of the beating of the tom-tom in an oriental temple, or in the monotonous cries which accompany an Indian war dance. Occidental or western music differs from oriental music mainly in the character of the sounds which are selected as being pleasing to the ear.

293. Some Musical Terms. (a) A *note*, as used in a musical sense, may refer to a sound having a definite pitch or to a symbol in an arbitrary scale. The word *tone* is often used in the same sense as the word *note*, referring to a sound of a definite pitch; or, on the other hand, it may refer to the sound resulting from a number of notes.

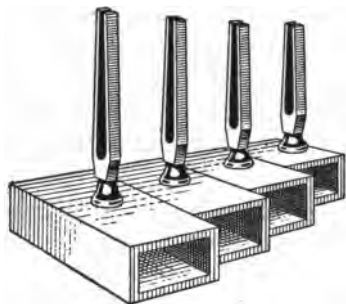


FIG. 280.—Four forks which sounded together give a major chord

(b) A *musical interval* is the ratio of the pitch (vibration number) of a given note to the pitch of another note. For example, the interval expressed by the ratio 1:1 is called *unison*; that expressed by the ratio 2:1, an *octave*. Thus if one note have a pitch due to 256 vibrations per second

and another 512 vibrations per second, we say that the pitch of the second is an octave higher than the first.

(c) When any three notes having ratios 4:5:6 are sounded together they produce a tone which is pleasing to the ear; the

same is true also of the ratios 10:12:15. A *major chord* consists of four notes having ratios 4 : 5 : 6 : 8, represented in music as *do, mi, sol, do'*. In Fig. 280 there is shown a set of four forks which sounding together give a major chord. A *minor chord* consists of four notes having the ratios 10 : 12 : 15 : 20. From the major and minor chords we derive our musical scales.

294. The Diatonic Scale. The *diatonic scale* or *gamut*, as it is sometimes called, consists of a series of eight notes having definite ratios. The scale derived from the major chord (ratios = 4 : 5 : 6 : 8) is called the *major diatonic scale*; that based on the minor chord (10 : 12 : 15 : 20) is called the *minor diatonic scale*. There is given below the major diatonic scale, Fig. 281.

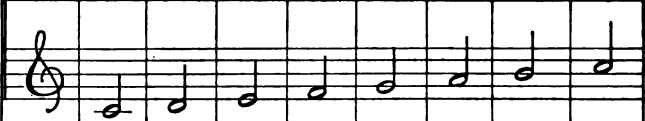
								
Name	DO	RE	MI	FA	SOL	LA	TI	DO
Letter	C	D	E	F	G	A	B	C'
Ratio	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Interval	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$	

FIG. 281.—Diatonic scale

Intervals between any two notes having the ratios $\frac{9}{8}$ or $\frac{10}{9}$ are called *whole tones*; intervals having the ratios $\frac{16}{15}$ are called *half tones*. It will be noted that in the diatonic scale shown in Fig. 281 there are five whole tones and two half tones in an octave from *C* to *C'*.

In physics we assign to middle *C* a frequency of 256 vibrations per second. Beginning with *C* as 256, the next note, *D*, is $\frac{9}{8} \times 256 = 288$; *E* $\frac{5}{4} \times 256 = 320$, and so on. The notes of the scale in the key of *C* are then,

Key of C	C	D	E	F	G	A	B	C'
	256	288	320	341	384	426	480	512

The scale may be extended above or below this octave by again using the ratios $9/8$, $5/4$, $4/3$, etc. For example, the note which is an octave above C' , that is C'' , makes $2 \times 512 = 1024$ vibrations per second; the note an octave below C makes $\frac{1}{2} \times 256 = 128$ vibrations per second.

In music the standard of pitch commonly employed is that which assigns to A 435 vibrations per second. This is called the *international standard of pitch*, and is that to which most musical instruments are tuned.

295. Tempered Scale of the Piano. In producing tones on the violin, the trombone, or with the human voice, it is possible to secure all gradations of pitch within a given range. In the case of an instrument like the piano which has a fixed keyboard, however, it is necessary to agree upon some arbitrary ratio from note to note. In fixing the ratios from note to note on the piano, musicians have agreed to adopt a system known as *equal temperament*; that is, the ratios between all notes are equal. The ratio selected as being most satisfactory is the twelfth root of 2, which is equal to 1.05946. Thus, if we fix the value of the note A , Fig. 282, as 435, then the sharp of A , the note of the black key next above it, will be $1.05946 \times 435 = 460.9$; the next key B will be $1.05946 \times 460.9 = 488.3$, and so on.

The keys representing an octave on a piano are shown in Fig. 282, there being eight white and five black keys. The



FIG. 282.—The thirteen keys comprising an octave on the piano

black keys represent notes called sharps and flats. A *sharp* is a note having a vibration number higher than that of a given note; a *flat* is a note having a vibration number lower than the given note.

Thus, the first black key above C is the sharp of C and the flat of D . These thirteen notes, eight white and five black, constitute an octave.

296. Quality of Sound. Sounds may differ in three respects; namely, (a) in loudness, (b) in pitch, (c) in quality. What we mean by quality or timbre may be illustrated as follows: If middle C, for example, be simultaneously struck on a piano, a violin, and a cornet, the pitch is the same in all three cases; and this may likewise be true of the loudness of the three sounds. We would have no hesitation, however, in assigning one sound to the piano as its source, another to the violin, and the third to the cornet. This property which enables us to assign a musical sound to a definite source is called *quality* or *timbre*. The quality of a musical sound is due to the number and character of the overtones present (Art. 298) and is determined by the form of the resulting sound wave.

VIBRATION OF STRINGS

297. Segmental Vibration of Strings. (a) If one end of a long flexible rope be fastened to the wall and the other end moved up and down by the hand in such a way that the rope is caused to swing as a whole, in somewhat the same manner as when used by children in "skipping rope," we will have an example of a string vibrating in a single segment, Fig. 283. The rope does not vibrate in a vertical plane, but has a somewhat circular motion;



FIG. 283.—String vibrating as a single segment, giving its lowest tone or fundamental

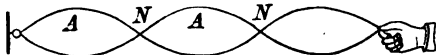


FIG. 284.—String vibrating in three segments, showing nodes and antinodes

this is true, also, of all vibrating strings. If now the hand be moved more rapidly, the rope may be made to break up into two, three, or more segments, as shown in Fig. 284, depending upon the rate at which the impulses are imparted. The

points of least motion, N and N , are called *nodes*; the points of greatest motion, A and A , are called *antinodes*.

298. Fundamental, Overtones, and Harmonics. When a string vibrates as a single segment it gives off its lowest or fundamental tone. The *fundamental* of any sounding body is the tone of lowest pitch which the body is capable of giving. When a vibrating string breaks up into segments, as shown in Fig. 284, it gives off tones which are higher in pitch than the fundamental; these higher tones are called *overtones*.

In Fig. 285 we have some excellent photographs of a string vibrating successively in two, three, and five segments. In

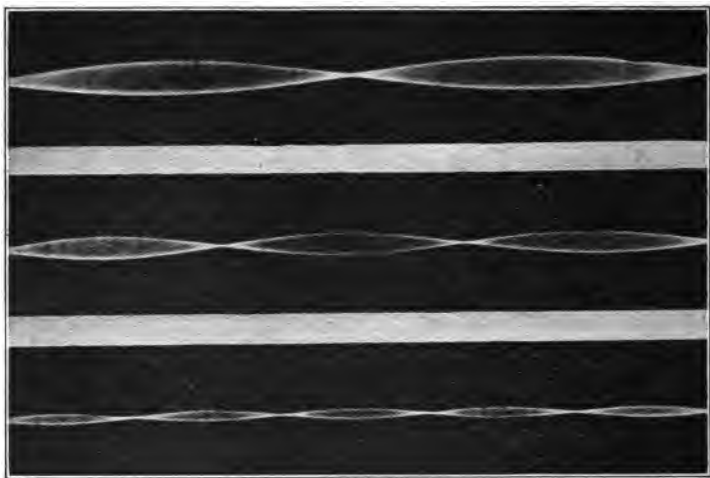


FIG. 285.—Photographs of a string vibrating successively in two, three and five segments

the first case (two segments) the pitch of the note emitted is twice as high as the fundamental, that is, one octave above the fundamental; in the second case (three segments) the note is three times that of the fundamental; and in the third case (five segments) the pitch is five times that of the lowest note (fundamental).

The illustrations shown in Fig. 285 represent segmented vibrations which are simple exact multiples of the vibration producing the fundamental. A string, however, may, and frequently does, vibrate in a very complicated manner, Fig. 286, producing complex tones. The overtones resulting from these complex vibrations do not always combine with the fundamental to produce tones which are pleasing to the ear. It has been found that those overtones which are exact mul-



FIG. 286.—Photograph of a string producing a complex tone

tiples of the fundamental, that is, overtones the frequencies of which are 2, 3, 4, 5, times the fundamental combine with the fundamental to produce harmonious tones, and hence are called harmonics. A *harmonic* is an overtone the frequency of which is an exact multiple of the fundamental. For example, if we sound together such a series of notes either with tuning forks or on the piano, it will be found that they combine together so harmoniously that it may be difficult to distinguish one from the other. The term harmonic is, therefore, a very appropriate one.

299. The Sonometer. The *sonometer* is an instrument used in studying the laws of vibration of strings. It is a hollow wooden box upon which is stretched

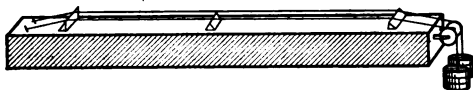


FIG. 287.—Sonometer

a number of strings. A spring balance or weight is used to

determine the stretching force acting on the string while a small wooden "bridge" is employed to vary its length. By

means of an instrument similar to the one shown in Fig. 287 the following laws may be verified.

300. Laws of Vibration of Strings. I. *The pitch of a string varies inversely as its length.* The shorter the string the higher the pitch. For example, if a string one meter long gives a pitch due to 100 vibrations per second, then the same string half a meter in length, the stretching force being constant, will give a pitch an octave higher than the first; that is, a pitch due to 200 vibrations per second.

II. *The pitch of a string varies directly as the square root of the stretching force.* If a string stretched by a force of one kilogram make 100 vibrations per second, then the same string stretched by a force of 4 kilograms will make 200 vibrations per second; that is, $100 : 200 = \sqrt{1} : \sqrt{4}$.

III. *The pitch of a string varies inversely as the square root of the mass per unit of length.* Thus for a given length and stretching force, the lighter the string the higher will be the pitch.

These three laws may be expressed mathematically by the following equation:

$$n = \frac{1}{2l} \sqrt{\frac{F}{m}}$$

in which n is the frequency, l the length of the string in centimeters, F the stretching force in dynes, and m the mass of the string in grams per centimeter of length.

Example. A string 1 m in length, and having a total mass of 2 grams, is stretched by a force of 2 kg. Find the frequency of the string when it is sounding its fundamental. *Solution:* The length $l = 100$ cm; $F = 2000 \times 980$ dynes; $m = 2/100$ grams per cm. Then $n = 1/200 \sqrt{196,000,000/2} = 49.5$ vibrations per second.

VIBRATION OF AIR IN PIPES

301. Vibration in Pipes. Musical instruments may be divided into two great classes: (a) stringed instruments and

(b) wind instruments. The notes which are produced by wind instruments are due to the vibration of air columns within them. We commonly speak of a wind instrument as a pipe.

The various kinds of wind instruments differ chiefly in the mode of excitation of vibration of the enclosed column of air. The part of the instrument in which the vibrations are excited is called the mouthpiece. Mouthpieces are of three types: (a) Those in which the air is blown across a sharp edge or across an opening, as in the flute or organ pipe. This form of excitation may be illustrated by blowing across the mouth of a small bottle, or better still, a discharged cartridge shell. A common tin whistle illustrates fairly well the principle of construction of the organ pipe. (b) Those in which the air is forced through an opening which is partly closed by an elastic tongue or reed, as in the cabinet organ and the accordion. An excellent illustration of the reed instrument is that furnished by the common "mouth organ," or harmonica. (c) Those in which the air is forced through a slit, formed by two elastic membranes, as in the case of the vibration of the air as it is forced between the lips in playing the cornet, or the vibration of the vocal cords in the production of voice.

302. Open and Closed Pipes. An *open pipe* is one that is open or free at both ends. In Fig. 288 there is shown an open organ pipe; at one end there is an open mouthpiece, at the other an open or free passage.

In Fig. 289 we have a *closed pipe*. There is at one end an open mouthpiece, similar to that of the open pipe; the other end, however, is closed.

In Fig. 290 there is shown a set of four open organ pipes, which when sounding their fundamentals produce a major chord; that is, they sound the notes *do*, *mi*, *sol*, *do'*.

With reference to its fundamental, an *open pipe* gives a pitch an octave higher than a *closed pipe* of the same length. This may be demonstrated in the following way: Blow gently into

the mouthpiece of an open pipe, Fig. 288; the pipe will give forth its lowest or fundamental tone. Now place the hand over the open end of the pipe, thus converting it into a closed pipe; it will now sound a tone which is one octave lower than that given by the open pipe, provided of course that the fundamental is sounded in each case.

The pitch of a given pipe depends upon its length; in general, the shorter the pipe the higher

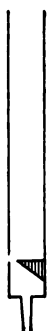


FIG. 288



FIG. 289

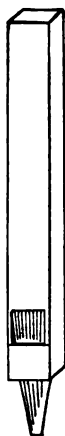
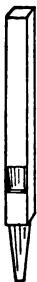


FIG. 290

Open and closed pipes



FIG. 291

the pitch. The relation of the length of a pipe to its pitch may be strikingly demonstrated by using a pipe into one end of which is fitted a movable piston, Fig. 291. If the piston be placed at the upper end, and a steady stream of air be blown into the mouthpiece, a tone having a definite pitch will result. If now the plunger be moved downward the pitch will rise, becoming very shrill as the plunger approaches the mouthpiece. By a single downward and upward motion of the piston the pitch may be made to rise and fall, illustrating the rise and fall of the pitch of a siren whistle.

The length of an open pipe is *one half* the wave length of the fundamental sound emitted.

The length of a closed pipe is *one fourth* the wave length of the fundamental sound emitted.

303. Overtones in Pipes. If we blow gently upon a pipe, it will give forth its fundamental tone. If now we blow more vigorously the pipe will give a tone an octave higher, that is, will sound its first overtone; blowing still harder, it is possible to make the pipe sound other and higher overtones.

An *open pipe* is capable of giving a complete series of overtones, having frequencies 2, 3, 4, 5, etc., times that of the fundamental.

A *closed pipe* is capable of giving only those overtones whose frequencies are 3, 5, 7, etc., times that of the fundamental.

304. Nodes and Antinodes in Pipes. We have learned that a pipe may be made to give forth not only its fundamental tone but also a series of overtones. What happens in the pipe in the case of the production of overtones is somewhat analogous to that which occurs in a string when it breaks up into segments and gives off its overtones. The air column within the pipe may be made to break up into segments forming nodes and antinodes.

We have said that a node in a pipe is somewhat similar to that in a string. A node in a pipe, however, differs from a node in a string in one very important particular. A node in a string is a point of least motion; *a node in a pipe is a point not only of least motion but also of greatest change of pressure.*

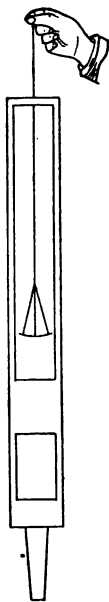


FIG. 292
Experimental
determination of the
position of a node in
a pipe

The presence of nodes in pipes may be determined experimentally by lowering into the pipe a small paper disc upon which has been placed a few grains of fine sand, Fig. 292. When the disc reaches a node (point of least disturbance) the sand is undisturbed; when the disc reaches an antinode (point of greatest disturbance) the sand is violently agitated.

305. Nodes in Open Pipes. Fig. 293 shows the position of the nodes in the production of the fundamental and the first two overtones of an open pipe. In pipe *A*, sounding its fundamental, the node is at the center and the length of the pipe is one-half the wave length of the sound emitted. In pipe *B*

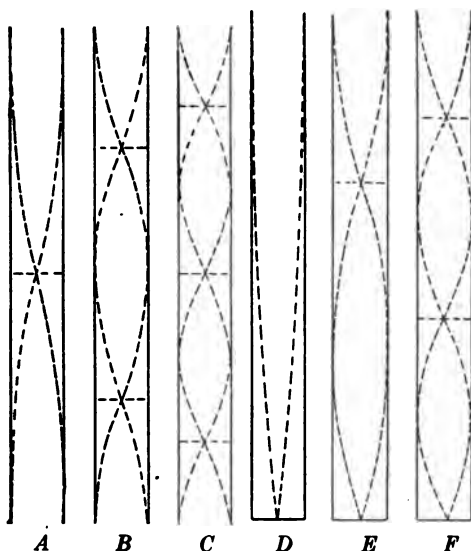


FIG. 293
Nodes and antinodes
in open pipes

there are two nodes, hence the pipe is sounding its first overtone; that is, it gives a pitch one octave higher than *A*. In pipe *C* there are three nodes; the pipe is sounding its second overtone.

In open pipes there is always an antinode at each end and one or more nodes within the pipe. Also, open pipes are capable of sounding in addition to their fundamental tone their first, second, third, fourth, fifth, etc., overtones.

FIG. 294
Nodes and antinodes
in closed pipes

306. Nodes in Closed Pipes. Pipe *D*, Fig. 294, represents a closed pipe sounding its fundamental; *E* represents the same pipe giving its first overtone, the vibration rate of which is three times that of the fundamental; *F* is sounding the next overtone, which is five times the vibration rate of *D*. Closed pipes are capable of giving only the first, third, fifth, etc., overtones.

ANALYSIS OF MUSICAL SOUNDS

307. The Phonodeik. Many instruments have been devised for the optical analysis of sounds. One of the most sensitive instruments of this sort is that known as the *phonodeik*, designed and perfected by Professor D. C. Miller. An outline section of this wonderfully sensitive instrument is shown in Fig. 295, in which h is the receiving horn; d is a sensitive diaphragm of thin glass, placed at the end of the horn; behind

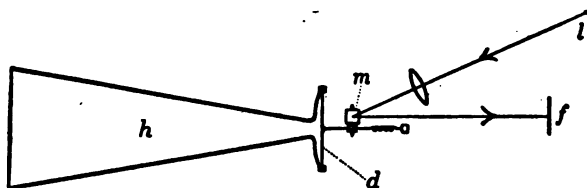


FIG. 295.—Outline section of the phonodeik

the diaphragm is a minute steel spindle mounted in jeweled bearings, to which is attached a tiny mirror m . A ray of light l is focused by means of a lens and reflected by the mirror m to a moving photographic film f . When the diaphragm d moves due to the action of a sound wave the

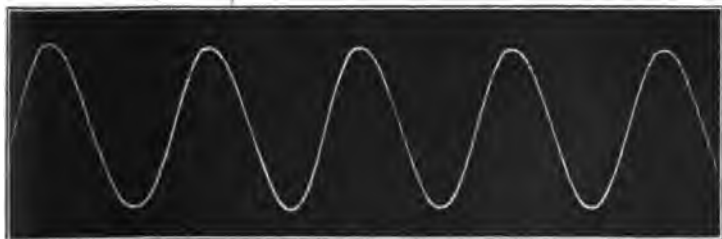


FIG. 296.—Photograph of a simple tone from a tuning fork

mirror m vibrates, thus causing the reflected beam of light to trace a record of the sound wave on the moving photographic film at f .

The word “phonodeik” means to show sound. The figures which follow are reproductions of the photographs of sound waves which were produced by Prof. Miller in his book “The Science of Musical Sounds.”

The musical instrument which gives the simplest and purest tone is the tuning fork. A photograph of the simple tone of a fork sounding

middle C ($n = 256$) is shown in Fig. 296, and a photograph of the complex sound from a bell in Fig. 297.

308. Tones from Stringed Instruments. The best known stringed musical instruments are the violin, piano, harp, guitar, banjo, and man-

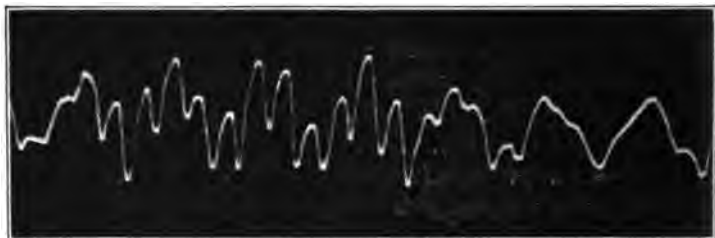


FIG. 297.—Photograph of the tone from a bell

dolin. We shall consider only certain typical tones as produced by the first two, namely, the violin and piano.

The violin. The strings of the violin are caused to vibrate by the to-and-fro motion of the bow; these vibrations are transmitted through the bridge and body of the instrument to the air. The great advantage of the violin over all the other orchestral instruments in expressiveness



FIG. 298.—Photograph of a typical tone from the violin

is due to the control by means of fingers and bow which the performer has over the tone production. In Fig. 298 there is shown what may be considered a typical form of a violin wave. Variations in bowing of the strings change the regularity of the vibrations and thus produce a con-

tinually changing wave form. In Fig. 299 we have a remarkable photograph of the tone of a violin at the time of the reversal of the bowing.

The piano. The vibrations in a piano originate in the strings which are struck by felt-covered hammers controlled by the keys. While



FIG. 299.—Photograph of the tone of a violin at the time of reversal in bowing

the vibrations originate in the strings, most of the sound comes from the sounding board to which the strings are attached. The piano is perhaps one of the most expressive instruments upon which one person can play, and hence it is undoubtedly the most popular musical instrument. Upon this instrument the skillful player can produce wonderful varieties of tone color in chords and groups of notes, resulting in music which is full, rich, and varied.

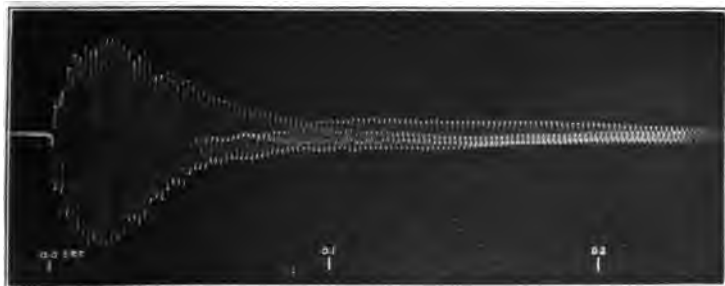


FIG. 300.—Photograph of the tone of a piano

In Fig. 300 we have depicted optically the tone of a piano. This photograph shows two important features, namely, first, that the sound rises to its maximum intensity in a mere fraction of a second, and, second, that it then gradually dies out with a progressing change in quality. In

relation to tone quality as produced on a piano, it is believed that the so called "artistic touch" of the musician consists in slight variations in the time of striking the different keys, as well as variations in the strength of the blows, and that tone quality is determined by purely physical and mechanical considerations. "The correctness of this argument," says Prof. Miller, "is further supported by the mechanical piano players, which attempt to reproduce the characteristics of individual pianists. The more highly developed such instruments become, the more nearly they imitate hand playing in musical effects; in many instances the imitation is practically perfect, and I believe that in the near future the automatic piano will reproduce all of the effects of hand playing."

309. Wind Instruments. *Organ pipe.* The organ pipe is one of the simplest of wind instruments. The pipe organ usually has a frequency of 16 vibrations per second for its lowest note and 4138 for its highest. An organ pipe giving a note due to 16 vibrations per second is nominally

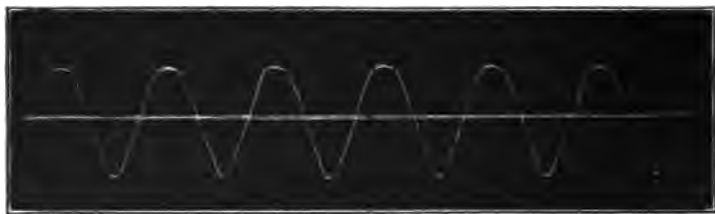


FIG. 301.—Photograph of the simple tone of a flute

32 feet long; that having a frequency of 4138 is 1.5 inches in length. There are a few organs in the world which have pipes 64 feet in length. A pipe of this length gives only 8 vibrations per second; such sounds, however, are hardly to be classified as musical tones, as they are heard as separated or discontinuous sounds.

The flute. The flute gives the simplest sound of any orchestral instrument. In Fig. 301 we have a photograph of one of a selected series of tones of a flute. Note the symmetrical outline of the particular curve, which in many respects resembles the simple curve given by the tuning fork, Fig. 296.

The flute tone may be described as sweet and tender. The poet Sidney Lanier, himself an accomplished flutist, in his poem "The Symphony" describes the tone of this musical instrument in the following beautiful lines:

"But presently
 A velvet flute note fell down pleasantly
 Upon the bosom of that harmony,
 And sailed and sailed incessantly,
 As if a petal from a wild rose blown
 Had fluttered down upon the pool of tone
 And boatwise dropped o' the convex side
 And floated down the glassy tide
 And clarified and glorified
 The solemn spaces where the shadows bide."

The clarinet. The clarinet generates sound by means of the vibration of a single bamboo reed in the mouthpiece. The body of the instrument has a uniform cylindrical base, at the lower end of which there is a bell shaped opening. Fig. 302 shows a photograph of a characteristic tone



FIG. 302.—Photograph of the tone of a clarinet

of the clarinet. Compare the complexity of this tone with the relatively simple tone of the flute, Fig. 301. The tones of this instrument possess a beautiful melting musical quality, well described by Lanier in "The Symphony" when he says,

"The silence breeds
 A little breeze among the reeds
 That seem to blow by sea marsh weeds;
 Then from the gentle stir and fret
 Sings out the melting clarinet."

The French horn. The horn is an instrument of extreme simplicity; it consists of a coiled brass tube, sometimes eighteen or more feet in length, bearing at the end a large flaring opening. The low sounds of the horn are rich in overtones, containing the largest number yet found

in any musical tone. The tone of a horn for the note D = 162 is depicted in Fig. 303.

The human voice. The sound of the voice originates in the vibrations of the vocal cords. The pitch of the voice is controlled largely by the



FIG. 303.—Photograph of the tone of a French horn

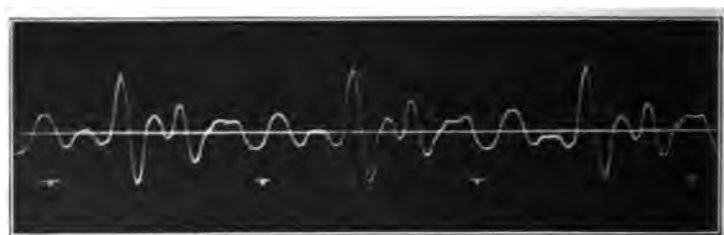


FIG. 304.—Photograph of the tone of a bass voice sounding the vowel *a*

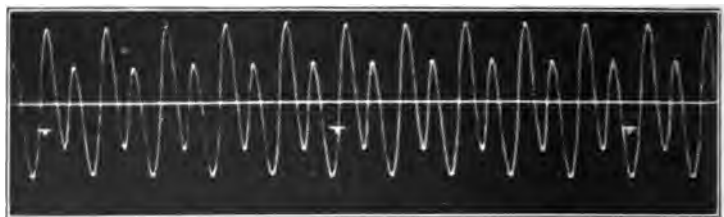


FIG. 305.—Photograph of the tone of a soprano voice sounding the vowel *a*

tension of the vocal cords, while the quality depends upon the resonance effects of the vocal cavities. Photographs of a bass voice and a soprano voice intoning the vowel *a* as in father are shown in Figs. 304 and 305 respectively. These two voices are very much unlike, as shown by their

respective curves, and yet the ear easily recognizes the same vowel in both.

In Fig. 306 we have a section of photographs of the sound waves created by the phonograph record reproducing the sextette from "Lucia di Lammermoor" as sung by six famous operatic stars. The wider parts of

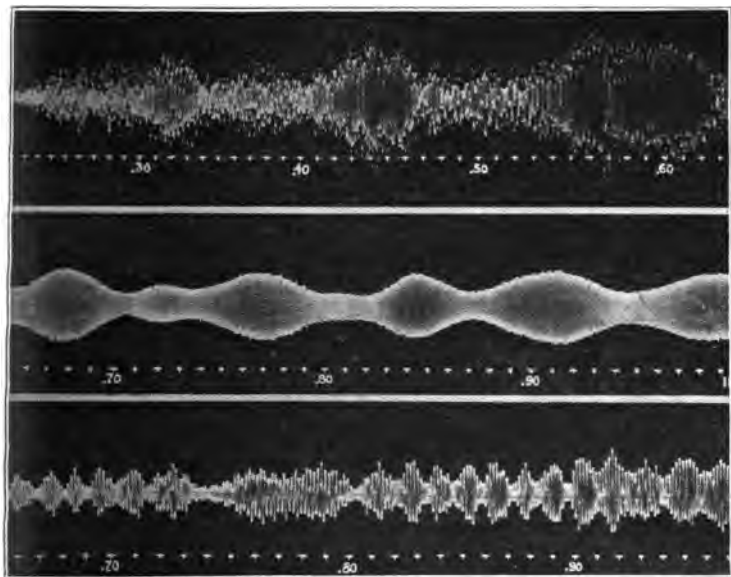


FIG. 306.—Photographs of a reproduction of the sextette from "Lucia di Lammermoor," showing voice curves as produced by Caruso (top), Tetrazinni and Amato

the upper picture are due to accented syllables as sung by Caruso. The curve of the second line is from the soprano voice of Tetrazinni, the fluctuations in width being due to a slight tremolo. The third curve is produced by the soprano, and the baritone Amato, singing softly.

310. The Vocal Organs. In the upper portion of the throat is a hard projecting mass commonly called "Adam's apple," which constitutes a part of the *larynx*, a box-like chamber formed of cartilages. The *larynx* is the primary organ of speech and song, and is of all musical instruments the most

wonderful, both on account of its simplicity as well as for its extreme delicacy of range. Across the upper end of the larynx there are stretched two muscular membranes, called the *vocal cords*. When the air is forced through the glottis, the vocal cords are thrown into vibration, which gives rise to the tones characteristic of the human voice. The vocal cords are controlled by muscles. When the edges of the cords are brought close together, that is, when the glottis is small, the vibration rate is high, hence the pitch of the voice is high; when the glottis is large the vibration rate is low, hence the tone is low. A longitudinal section of the larynx

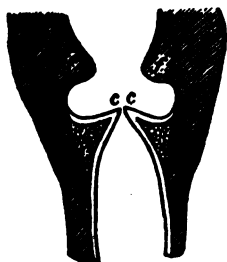


FIG. 307.—Section of the larynx, showing the vocal cords

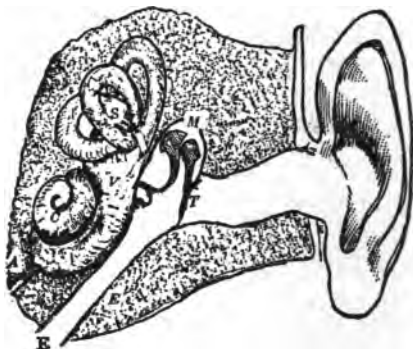


FIG. 308.—Mechanism of the ear

is shown in Fig. 307, *cc* representing the vocal cords. Just above the true vocal cords are two folds of mucous membrane, *ff*, called the false vocal cords.

The quality of the human voice is modified by the resonance cavities of the mouth and the nasal passage. If the nostrils be closed by the fingers and we attempt to recite the words "The moon is beaming," we will have strikingly illustrated the effects of changing the resonant properties of the nasal cavity.

311. The Organs of Hearing. The human ear consists of three parts or divisions: (a) the external ear, (b) the

middle ear, and (c) the internal ear, Fig. 308. The external ear includes the concha and the tube or canal terminating in a thin membrane called the drum membrane or tympanum *T*. The middle ear contains a chain of little bones, the function of which is to transmit vibrations from the tympanum to the internal ear. The middle ear communicates with the mouth chamber by means of a tube called the Eustachian tube *E*, the function of which is to equalize the pressure between the air in the middle ear and that on the outside. The internal ear is placed deep in the skull and consists of three parts: (a) the vestibule *V*, (b) the semicircular canals *S*, three in number, and (c) the cochlea, or snail shell *C*, all of which are filled with a watery fluid. In this watery fluid of the internal ear we find the nerve fibers, which spread out from the auditory nerve.

312. How We Hear. The process of hearing begins with the transmission of sound waves to the drum of the ear. These vibrations, it will be remembered, consist of condensations and rarefactions which produce upon the drum membrane changes of pressure, causing it to vibrate back and forth. The vibrations are then transmitted by the ossicles of the middle ear to the fluids of the internal ear, whence it is transmitted to the fibers of the auditory nerve. This disturbance of the end organs of the auditory nerve produces a nervous impulse which travels to the brain and there gives rise to the sensation of hearing.

313. Pitch Limits. *Human voice.* The range in pitch for the human voice in singing is from 60 vibrations per second for a low bass to about 1300 vibrations per second for a very high soprano. The range for the ordinary individual voice is about two octaves. The range of the voice of the trained singer, however, is frequently somewhat above two octaves. The lowest note which a bass voice can reach is about two octaves below middle *C*, or about 60 vibrations per second. The highest note which the ordinary soprano can reach is

about two octaves above middle *C*, or somewhat above 1000 vibrations per second. The pitch of a woman's voice is in general about twice as high as that of a man's voice. It must be noted however, that the range of each is practically the same, namely, about two octaves.

Piano. The range in pitch of the ordinary piano is somewhat over seven octaves, the lowest note having a frequency of 27 vibrations per second, and the highest 4138.

Organ pipe. The pipe organ usually has a frequency of 16 vibrations per second for its lowest note, and 4138 for the highest.

314. Limits of Audibility. The human ear is capable of hearing sounds covering a range in pitch of about ten octaves. The limits of audibility vary in quite a marked degree for different individuals. Some exceptional ears can probably hear as high as 40,000 vibrations per second. The ordinary upper limit, however, is about 30,000.

The lower limit for a continuous sound, that is, a musical tone, lies between 12 and 20 vibrations per second, the general consensus of opinion being that the lower limit for a musical tone is 16 vibrations per second. Of course the ear can hear sounds which have a vibration frequency lower than 16 per second, but they are heard as separated or discontinuous sounds.

TALKING MACHINES

315. Introductory. To the inventive genius of Thomas Edison we owe the two instruments which have done so much to enlarge the field of educative media as affecting the ear and eye, namely, the phonograph and the moving picture. The phonograph, invented by Edison in 1877, originally consisted of a rotating cylinder which recorded the movements of a diaphragm provided with a small needle by means of indentations in a sheet of tin foil supported over a spiral groove on a metal cylinder. In later machines the metal cylinder with its tin foil covering was replaced by a wax cylinder or disc. In the modern dictaphone, Fig. 309, the cylindrical wax receiver is still employed. Machines of the dictaphone type are designed to take the place of a stenographer in busi-

ness offices. The business man dictates into the receiver of the machine, the moving diaphragm with its tracing needle recording the sounds of his voice on the surface of a rotating wax cylinder. Later the typist allows the cylinder to rotate again under the needle, and the vibrating diaphragm gives forth the sounds of the words which were imparted to it. When the record has been received and written out on the typewriter, the surface of the wax cylinder is made smooth by means of a graving tool attached to the machine, and the cylinder is ready for a new record.

A modification of the cylinder type of phonograph was invented by Bell and Tainter; this machine was called the graphophone. Later on Berliner introduced the method of etching the original record on a zinc disc, producing the gramophone type. In the preparation of the gramophone disc, which is now the familiar disc record, the vibrating needle of the diaphragm is allowed to vibrate over the surface of a rotating greased zinc disc. The trace of the needle in the film of grease on the surface of the disc is then etched by means of an acid, and then a copper mold is made of the etched surface of the zinc by means of the electrotyping process. By means of this copper record hundreds of facsimiles of the original record may, by pressure and heat, then be made upon the hard rubber discs of commerce.

In accordance with common practice, we shall use the term "phonograph" to designate the various types of speech recording and reproducing machines.

316. The Phonograph. So far as simplicity of construction and perfection of execution are concerned, the phonograph is closely allied to the organs of human speech and hearing. This instrument is provided with a mouthpiece across one end of which there is placed a thin disc, usually of mica, to the center of which there is attached a needle. When it is desired to prepare a record, the diaphragm is adjusted so that the stylus or needle



FIG. 309.—Dictating to and transcribing from the Dictaphone

rests lightly upon the rotating cylinder or disc, as the case may be. Sound waves entering the receiver cause the diaphragm to vibrate, and this in turn causes the needle to trace out in the soft face of the rotating receiving surface an irregular path corresponding to the character of the sound waves impressed upon it. As explained in Art. 315 hard rubber copies of the receiving surface are now prepared in quantity, and the records are ready for use. When this hard surfaced record is caused to rotate under



FIG. 310.—Photograph of the tracing of the portion of a record of orchestral music

the needle or stylus of the machine the vibrating diaphragm gives forth the same wave forms as were impressed upon it, and talking, singing, or instrumental music results.

A photograph of the tracing on the portion of the surface of a record of orchestral music is given in Fig. 310.

A homely but striking analogy to the preparation of a phonograph record may be given as follows: A vehicle on a given day is driven over a soft rough road. As the vehicle moves forward a record of every jolt and vibration is left in the soft mud. Now suppose that the weather turns cold and the road freezes, thus preserving for a time at least the irregular path of the wheels of the vehicle which passed over it. Suppose further that while the road is still frozen the vehicle again passes over it, going in the same direction as on the previous trip. The vehicle now bumps up and down and vibrates back and forth in practically the same manner as on the day before. The record of the joltings and vibrations are thus preserved in frozen mud, in a manner somewhat analogous to the preservation of the voice or of a piece of music on the surface of a finished phonograph record.

The quality of tone given by a phonograph depends upon (a) the condition of the surface of the record, (b) the kind of needle used, (c) the speed of rotation of the disc, and (d) the resonant properties of the cavities and framework of the instrument.

317. Kinds of Records and Needles. With reference to the character of the tracing made upon a record by the producing needle, there are two kinds of records, known as (a) hill-and-dale records, and (b) lateral-cut records.

Hill-and-dale records. Records of this type are made by a needle which moves up and down vertically as the record passes under it. Such a record,

Fig. 311, is well described by the term "hill-and-dale." On such records a stylus having a rounded tip of diamond or sapphire, or other very hard substance, is commonly employed, as shown in Fig. 212. The advantage of such a stylus is that it may be used over and over again without change, and without injury to the record.



FIG. 311
Micro-photograph of a
hill-and-dale record



FIG. 312
Micro-photograph of the
rounded sapphire tip of a
stylus suitable for use in a
hill-and-dale record

Lateral-cut records. Another type of record is that known as the lateral cut or to-and-fro tracing, Fig. 313. In the grooves of a record of this type the needle vibrates back and forth laterally. With such records the best results usually are obtained by the use of a stylus having a wearing point



FIG. 313
Micro-photograph of a
lateral-cut record



FIG. 314
Metal and fiber needles
suitable for use on lateral-cut records

such as metal or fiber, Fig. 314. For good results the point should fit the groove in the record as accurately as possible. To obtain the best results with a lateral-cut record the needle should be sufficiently soft so as to wear from an approximate fit to a fairly accurate fit during the first

few turns of the disc. For the production of soft tones fiber needles are very satisfactory in this respect. Needles of this sort should be trimmed at the point before use on each record, by means of a special cutting instrument. In Fig. 315 there are shown micro-photographs of a steel needle point before and after use. Before use the point is slightly rounded and

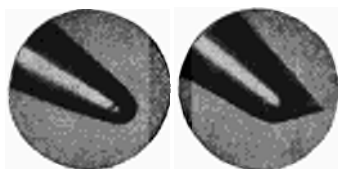


FIG. 315.—Metal needle before and after use

smooth. After use for some time it possesses sharp edges; in fact it is now a graving tool, which is capable of doing serious damage if applied to another record, or if removed from its support and then again applied to the same record. Such a worn needle may be used several times on the same record, however, without serious results, provided that between

two successive runs of the record the needle is not removed from its support.

318. Effect of Speed on Tone Quality. The tone quality given out by a phonograph is varied by changing the speed of the motor which turns the record. For example, when the vowel sound in the syllable *ma* is recorded, the greater part of the energy of the voice is emitted by tones having a frequency of about 924 vibrations per second. If now the tone is reproduced at the same speed as that at which it was recorded one hears the vowel sound as in *ma*. If, however, the speed of rotation is reduced so that the sound which previously had a frequency of 924 becomes 730, the syllable *maw* is produced. Further reduction in the speed of rotation produces successively the syllables *mow*, and *moo*. The relation of frequency, as affected by speed, to the vowel sound produced is given in the following:

Phonograph, frequency $n=$	924	730	444	311
Vocal sound	<i>ma</i>	<i>maw</i>	<i>mow</i>	<i>moo</i>

In order to get the most satisfactory results in tone quality from a given record, then, it is clear that the speed of the driving motor should be regulated so as to conform with the speed requirement as printed on the record.

319. Rules to be Observed in the Care and Operation of a Phonograph.

1. The motor should occasionally be inspected and oiled by one who understands its mechanism.
2. Records should be kept free from dust by brushing the recording surface with a soft brush.
3. Care should be exercised in the handling of records so as not to scratch or mar the surface tracings.

4. Hill-and-dale records should be played on a machine designed for up-and-down motion of the stylus; likewise, lateral-cut records should be played on a machine designed for lateral motion of the needle or stylus. The two types of records should never be interchanged unless a machine especially designed for the use of both kinds of records is available.

5. When a record is played on a machine assigned for both types (hill-and-dale and lateral-cut) care should be exercised to see that the recording stylus and diaphragm are properly set for the given record.

6. A soft needle when once used and removed from its support should be discarded.

7. Each record should be rotated at a speed which conforms as nearly as possible to that given in the printed instructions.

REVIEW EXERCISES

1. (a) Define transverse wave, longitudinal wave. (b) Give illustrations of each.

2. Explain the terms condensation and rarefaction, as used in connection with longitudinal waves.

3. Compare the motion of the wave with the motion of the vibrating particle in the case of (a) surface water wave; (b) a wave passing over a field of grain.

4. Define the term sound as used by (a) the psychologist, (b) the physicist, (c) Define acoustics.

5. Define and illustrate by a sketch (a) wave length, (b) amplitude of vibration.

6. Explain the meaning of the following equation, and define each term: $v = \sqrt{e/d}$.

7. Why does the timer in a 200 yard dash start his stop watch by the flash of the pistol rather than by its report?

8. Explain why an increase in temperature causes an increase in the velocity of sound in air.

9. What is the velocity of sound in air, in feet, at (a) 0°C (b) -20°C (c) $+20^{\circ}\text{C}$?

10. What is the approximate relation of the velocity of sound in air to that in water? Iron?

11. Explain why the velocity of sound in metals is greater than that in air.

12. A flash of lightning is seen and 5 seconds later the thunder is heard. How far away is the lightning discharge, the temperature being 25°C ?

13. A sunset gun was fired at exactly 6:30 P. M. at a fort. What time was it when the sound was heard 20 miles away, the temperature being 20°C ?

14. The Eiffel Tower, Paris, is 1000 ft. high. A bell is struck at the top. In what time will the sound reach a point on the ground 1000 ft. from the center of the base, the temperature being 68°F ?

15. Give examples of reflection and refraction of sound.

16. Explain the echo. State how far the reflecting surface must be from the source of sound in order to produce an echo. Why?

17. Define: (a) reverberation, (b) coefficient of absorption, (c) absorbing power.

18. Explain each term in the equation $T = 0.164 V/a$.

19. (a) What is the distinction between intensity and loudness? (b) Upon what factors does the intensity of sound depend? (c) Discuss each briefly.

20. Explain why striking a bell a vigorous blow causes it to give off a louder sound than if it be tapped lightly.

21. Compare the intensity of a given sound at two points, one a half mile from the source, the other three miles from the source.

22. Define and give examples of free and forced vibrations.

23. Define resonance, and give an illustrative example.

24. Explain the meaning of each term in the equation $l = v/n$.

25. A closed resonance tube 2 ft. in length responds to a given fork when the temperature is 25°C . Find the frequency of the fork.

26. A closed resonance tube 18 in. in length responds to a fork which makes 320 vibrations per second. Find the temperature.

27. A closed organ pipe is 3 ft. long. (a) What is the wave length of its fundamental tone? (b) How long must an open pipe be to give a tone of the same pitch?

28. Define and give illustrations of beats.

29. Make drawing to illustrate the effect of sound waves upon each other such that they produce (a) a louder sound, (b) silence, (c) beats.

30. Define pitch, and explain how a siren may be used to determine the pitch of a sounding body.

31. A current of air is blown against the disc of a siren having a row of 30 holes, while the disc is making 120 revolutions per minute. (a) What is the pitch of the resulting tone? (b) If the speed of the siren were doubled, how will the pitch be affected?

32. A whistle in sounding makes a certain number of vibrations per second, which strike the ear of a person who is standing still. Suppose now that the person walk toward the whistle. Will the number of vibrations falling upon his ear per second be increased or diminished? How

will it affect the pitch? How do you account for the rise of the pitch of a locomotive whistle which is rapidly approaching?

33. Define: music, musical interval, octave, major chord, minor chord.

34. (a) Define diatonic scale. (b) Name in order the eight notes of which it is composed.

35. How many notes per octave are there in the tempered scale of the piano? What do the black keys represent?

36. (a) What is the ratio from one key to the next on the piano? (b) What name is given to a system of tempering in which the ratios are all equal?

37. Make drawing to illustrate nodes and antinodes in the case of the vibration of strings.

38. (a) Define fundamental tone, overtone, harmonic. (b) When a string vibrates both as a whole and in parts at the same time, what can you say of the character of the tone given off?

39. (a) In what three ways may sounds differ? (b) Define and illustrate quality of sound.

40. (a) State the laws of vibration of strings. (b) Explain each term of the equation $n = \frac{1}{2l} \sqrt{\frac{F}{m}}$

41. How will the pitch of a string be affected (a) if its length be doubled? (b) if its tension be quadrupled? (c) if the mass be increased nine times?

42. A given string stretched by a force of 16 lb. makes 256 vibrations per second. What will be the vibration rate if the stretching force be increased to 25 lb.?

43. A string 1 m long makes 512 vibrations per second. What will be the frequency of the string if its length be decreased by 25 cm?

44. (a) What is the relation of the length of a pipe to its pitch? (b) What is the relation of the pitch of an open pipe to that of a closed pipe?

45. An open pipe of given length is sounding its fundamental. Suppose that a person stop one end by means of a card. How will the pitch be affected?

46. Define node in a pipe, and tell wherein it differs from a node in a string.

47. How may the presence of nodes in pipes be determined experimentally?

48. When a closed pipe is emitting a note what always occurs at (a) the closed end? (b) The open end?

49. Make sketches to illustrate the position of nodes in open pipes (a) for the fundamental, and (b) the first and second overtones.

50. Make sketches to illustrate the position of nodes in closed pipes, (a) for the fundamental, and (b) overtones.

51. Make sketch and describe briefly the vocal organs. Explain the condition of the cords when the pitch of the voice is (a) high, (b) low.

52. (a) Make sketch of the ear, and describe how changes of pressure due to condensations and rarefactions of sound waves are transmitted from the external to the internal ear. (b) Describe the Eustachian tube, and explain briefly its function.

CHAPTER VIII

LIGHT

NATURE OF LIGHT

320. Introductory. The sun is not only the most familiar source of light, but it is also the earth's chief source of energy. All the energy of plant and animal life is directly traceable to the sun, as is also the energy furnished by wind and water power. The energy of our coal fields, too, is nothing more than the stored-up energy of the sun's rays of by-gone ages. Now the sun is some 93,000,000 miles from the earth, and the question may be asked: How does this energy get to the earth across the enormous gulf of intervening space? In general three theories have been advanced to explain the transmission of the sun's energy; namely, (a) the emission theory, (b) the wave theory, and (c) the electromagnetic theory.

The *emission or corpuscular theory*, which was advocated by Sir Isaac Newton, assumed that the energy of the sun is carried through space by tiny particles or corpuscles which are shot off from that body with an enormous velocity, and which carry energy somewhat as a bullet carries energy from a gun. This theory is no longer held by scientific men.

The *undulatory or wave theory*, which was first definitely stated by Huygens, a Dutch physicist, in 1678, and which with certain modifications is now generally accepted, assumes that the energy of the sun is transmitted through space by means of waves, through a medium called the "ether."

In 1864 Maxwell, an English physicist and mathematician, advanced a theory that it ought to be possible to create ether waves similar to light waves by means of electrical disturbances. Later on this theory was confirmed experimentally by Hertz.

Maxwell's theory is known as the *electromagnetic theory of light*.

321. The Ether. The *ether* is supposed to be a medium which fills all space, not only between the heavenly bodies, but also between the molecules of matter itself, and which is capable of transmitting energy. It seems to offer no resistance to the passage of bodies through it, since in all the centuries in which astronomers have been making accurate observations of the heavenly bodies no retardation has ever been observed. No one has even seen the ether or felt it or weighed it; nevertheless it is convenient to *assume* that such a medium does exist in order to explain the phenomena of light, radiant energy, and electricity.

We do not know positively that such a medium as the ether really exists; we only assume that it exists. We cannot, then, speak with any degree of definiteness of its properties; indeed the properties of the ether are as much a question of dispute today as they were in the days of Newton. While, then, it is convenient and even necessary to assume that there is some such medium by means of which radiant energy may be transmitted, we should nevertheless be very careful not to allow our assumptions to come to be regarded as facts. In this text, therefore, we speak of the ether merely as a medium capable of transmitting energy, without specifying whether this transmission is due to the elastic properties of the medium, to strain tubes, or to any other specific means whatsoever.

322. Wave Theory of Light. The wave theory of light assumes that the energy of the sun and other light giving bodies is transmitted through space by means of waves which travel outward from the source, in a medium of uniform density, in the form of concentric spherical waves. Such a propagation of light waves may be represented on a flat surface by a series of concentric circles as shown in Fig. 316, in which *L* is the source of light. The line *LA* is drawn to represent

the direction of propagation of a given set of wave fronts, as *ab*.

It is important here to note that only a part of the energy that comes from the sun by means of ether waves is capable of affecting the eye and thus producing the sensation of sight. Ether waves from the sun may be divided into three classes: (a) relatively long waves which produce the sensation of heat; (b) short waves which affect the eye, producing the sensation of sight; and (c) very short waves which do not affect the organs of sight but which are capable of giving rise to chemical reactions, such for example as those which may affect a photographic plate. Now while it is not always customary to do so, we shall in this text, for the sake of clearness, refer to those waves which affect the eye as light waves.

Light waves differ from sound waves in several very important particulars:

(a) Light waves are transmitted through a hypothetical medium called ether; sound waves are transmitted only through matter. Light can be transmitted through a vacuum; sound can not. (b) Light waves are transverse; sound waves in fluids (air and water) are longitudinal. (c) Light waves are exceedingly short; sound waves are relatively very long. For example, waves of yellow light are only 0.0000589 centimeter in length, while the length of sound waves in air are more than 2,000,000 times as great. (d) The speed of light is more than a million times as great as that of sound. (e) And, finally, light affects the eye; sound, the ear.

323. Definitions. (a) A *luminous* body is one which emits light. The sun and the stars are luminous bodies; so, too, is a candle flame or the glowing filament of an incandescent lamp. Bodies which shine by light other than their own are

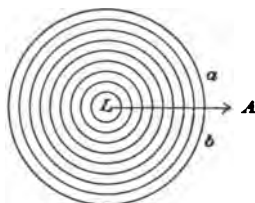


FIG. 316.—Light waves travel outward in all directions from the source *L*

called *illuminated* bodies. The moon is a good illustration of an illuminated body. A *transparent* body is one which allows light to pass through it readily; that is, it is one which we can see through, as, for example, window glass. A *translucent* body is one which allows only a part of the light to pass through without permitting objects to be distinctly seen, as in the case of "frosted" glass. An *opaque* body is one which does not allow light to pass through it. It must be noted in this connection that the terms transparent, translucent, and opaque are used in a purely relative sense. Wood, for example, is opaque, yet a shaving from a pine board may be obtained so thin as to be almost transparent. Gold may be beaten out into sheets so thin as to be translucent.

(b) *Optics* is the branch of physics which treats of light. *Light* may be defined as a vibratory motion which is capable of affecting the organs of sight.

(c) A *ray*, *LA*, Fig. 316, is a line drawn to represent the direction of propagation of a wave front, *ab*. A *beam* of light is a number of parallel rays, Fig. 317. A *pencil* of light is

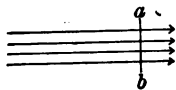


FIG. 317
Beam of light

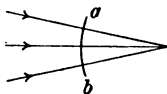
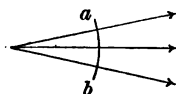


FIG. 318
Converging and diverging pencils of light



a number of rays passing through a point called the focus, Fig. 318. In Fig. 318 there is represented a *convergent pencil* of light and a *divergent pencil*. The wave front in each case is represented by the curved line *ab*.

324. Shadows. Light travels in straight lines, provided the medium through which it is propagated is *homogeneous*, that is, provided the medium has the same density and elasticity throughout. The fact that light travels in straight lines is seen when a beam is passed into a darkened room in which there are particles of dust floating in the air. The marksman

in sighting his gun, the surveyor in adjusting his instruments, and the mechanic in much of his work, all take account of this fundamental property of light; namely, that it travels in straight lines.

If an opaque object be held in front of a luminous body there appears in the rear of the opaque body a dark space called a *shadow*, which has three dimensions: length, breadth,

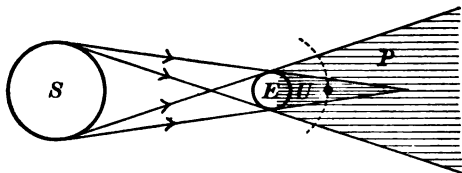


FIG. 319.—Shadow, showing umbra and penumbra

and thickness. That portion which appears on the wall or screen is called a section of the shadow. A shadow may consist of two parts, the *umbra* and the *penumbra*. Figure 319 shows the umbra *U* and penumbra *P* of the shadow cast by the earth. In an eclipse of the moon this body passes through the cone of the earth's shadow, entering the penumbra first and leaving it last.

325. The Velocity of Light. For a long time it was thought that light was transmitted through space instantaneously. In 1675, however, Roemer, a young Danish astronomer, who was studying the satellites or moons of Jupiter at the observatory at Paris, came to the conclusion that light travels through space with a definite finite speed. According to his determination, the velocity of light (transmission in a given direction) is about 186,000 miles per second. Roemer's famous discovery came about somewhat as follows: The planet Jupiter has several moons which revolve about it as our moon does about the earth. The inner one of these satellites passes into the shadow cast by Jupiter, Fig. 316a; that is, it is eclipsed

once on an average every 42 hours, 28 minutes, 36 seconds. Roemer calculated in advance the exact time that each eclipse should occur for a number of positions of the earth in its orbit. He took a series of observations as the earth moved from *E* away from Jupiter and found the eclipses occurred at regu-

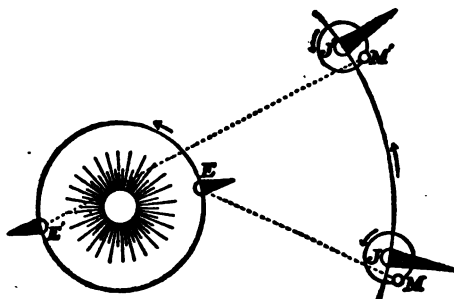


FIG. 319a.—Illustrating Roemer's method of determining the speed of light

larly increasing intervals later than those which he had computed. When the earth had reached the point *E'*, directly across its orbit from Jupiter, the eclipse occurred about 1000 seconds later than the computed time. He concluded that this apparent delay in the

time of the eclipse was due to the time required for light to travel across the earth's orbit a distance of about 186,000,000 miles. Now $186,000,000/1000 = 186,000$: that is to say, *the velocity of light is 186,000 miles per second.*

Roemer's wonderful discovery was received with but little favor by the scientific men of the day; indeed, it was practically disregarded for over fifty years until other methods were discovered for measuring the speed of light and his figures were thus verified.

326. Velocity of Light in Different Media. According to Newton's corpuscular theory, light should travel faster in a dense medium, such as water or glass, than in a rare medium; according to the wave theory, on the other hand, light should have the greater velocity in a rare medium. Therefore, when in 1850 Foucault, a French physicist, measured, by means of a rotating mirror, the speed of light in air and water, and found thereby that its velocity is greater in air than in water,

he thus established on a firm basis the undulatory or wave theory which is now generally accepted.

Undoubtedly the most precise determination of the velocity of light was that made by Prof. Michelson of the University of Chicago. Michelson's value gives to light a velocity of 299,860 kilometers per second. Both Foucault and Michelson demonstrated by laboratory methods that the speed of light is greater in a vacuum than in air, and greater in air than in water or glass.

EXERCISE. 1. Michelson's value of 299,860 kilometers per second is equivalent to how many miles per second?

327. Images Formed through Small Apertures. If a candle or other luminous body be placed in front of a small aperture in an opaque screen, Fig. 317*a*, there will be formed upon a second screen *S* an inverted image of the body. The following points with respect to the formation of images through apertures are to be noted: (a) The image is inverted and perverted; that is, it is upside down with respect to the object and the right side of the image corresponds to the left side of the object. This is due to the fact that rays of light from

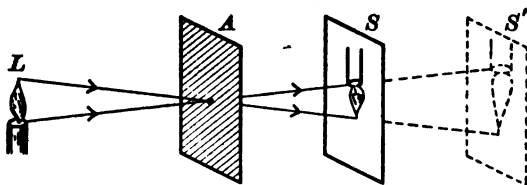


FIG. 319*b*.—Inverted images formed through a small aperture

the different points of the object pictured on the screen cross as they pass through the aperture. (b) The size of the image depends on the distance of the screen from the aperture. (c) The smaller the opening the less the illumination of the image but the greater the distinctness of outline; on the other hand, as the aperture becomes larger the illumination of the

image increases but its distinctness diminishes, due to the overlapping of the rays.

The principle of the formation of images through small apertures is made use of in the employment of the so-called

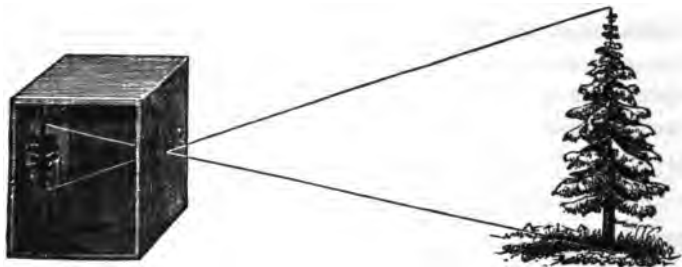


FIG. 319c.—Pinhole camera

pinhole camera in photography. This apparatus consists of a small box painted black on the inside to prevent undue reflection of the light which is admitted through a small aperture or "pinhole." The photographic film is placed in the



FIG. 319d.—This picture was taken with a pinhole camera

rear of the box in such a way as to receive the image of the object outside, as illustrated in Fig. 319c. A camera of this type is very inexpensive and may be employed in photographing landscapes and other scenes when long exposures may be secured. In Fig. 319d there is shown a picture taken by such a camera.

328. Intensity of Illumination. By *intensity* of illumination we mean the quantity of light per unit area. Experience teaches us that the farther one is away from a given source of light the less intense the

illumination becomes. This is due to the divergence of the rays, as shown in Fig. 320.

Consider screen S to be one foot from the source of light L and screen S' to be two feet from the source. Now the quantity of light which falls upon each screen is the same. The rays falling on S' , however, are spread out over four times as much space as on S ; therefore the intensity of illumination on a unit surface of S' is only one-fourth as great as that on S . This is an illustration of the law of inverse squares, which states that the intensity of illumination is inversely proportional to the square of the distance from the source.

This may be written

$$\begin{aligned} \text{intensity at } S &: \text{intensity} \\ \text{at } S' &= d'^2 : d^2 \end{aligned}$$

in which d is the distance of screen S from L , and d' is the distance of S' from L .

EXERCISES. 2. How does the quantity of light on screen S compare with that on S' ?

3. Suppose that S is 2 feet from L , and S' 4 ft. How does the intensity of illumination on screen S compare with that on S' ? How will the intensities on the two screens compare if S' be placed at a distance of 3 ft. from L ?

329. The Photometer. A *photometer* is an instrument for measuring the intensity of light. The unit of intensity is the *candlepower* (*cp*), which is the light given out by a standard candle. The common incandescent electric light of the carbon filament type is usually of 16 candlepower.

The Bunsen photometer, Fig. 321, consists in principle of a paper screen A , upon which there is a small circular oil or

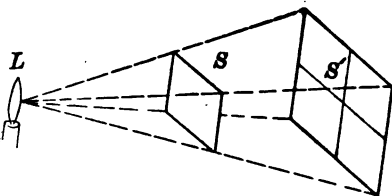


FIG. 320.—Illustrating the law of inverse squares

grease spot. If the paper with the grease spot upon it be held up to the light, in front of an open window, for example, so that the paper is between the light and the eye, the grease spot will appear lighter in color than the paper because it is more transparent. Now if the paper disc be held up in front of a dark body, such as a blackboard, the grease spot will appear darker than the paper, because it reflects less of the

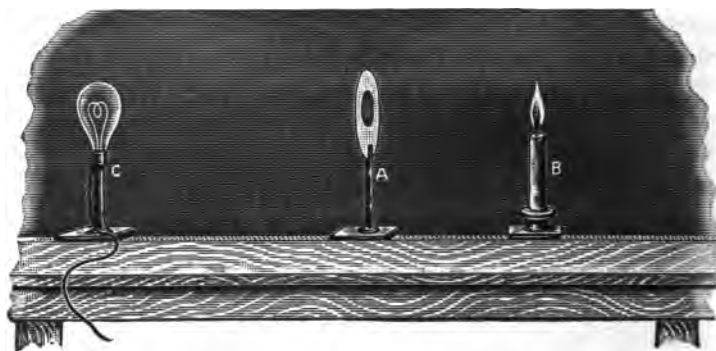


FIG. 321.—Bunsen photometer

light than does the paper. When the intensity of illumination on both sides of the paper disc is equal the difference in color between the two faces of the grease spot is reduced to a minimum.

To determine the intensity of light by means of this apparatus we proceed somewhat as follows: A standard candle is placed at a given distance from the screen, 1 foot say; the light, the intensity of which is to be measured, is placed on the other side of the screen and then moved back and forth until a position is found at which the spot on the screen is equally illuminated from both sides. From the law of inverse squares we may now determine the intensity of the given light in terms of its distance from the screen. If the candle is 1 foot from the screen and the light 4 feet distant, their relative intensities

are as $1^2 : 4^2 = 1 : 16$. Thus we say that the intensity of the light C is 16 candlepower.

There are at the present time two kinds of candlepower standards: (a) the *flame standards* of Great Britain, France, and Germany, and (b) the *electric standards* of the United States. The flame standards are the Pentane lamp of Great Britain, the Bourgie decimale of France, and the Hefner lamp of Germany.

The American unit of candlepower is defined in terms of certain tested carbon filament incandescent lamps, kept at the Bureau of Standards at Washington. The *international unit of candlepower* = one American electrical unit = one Pentane unit = one Bourgie decimale = $10/9$ Hefner unit. The Hefner unit of candlepower is the light given by a horizontal beam from the Hefner lamp, burning pure amyl acetate, at normal atmospheric pressure (76 cm), in an atmosphere containing 8.8 liters of water vapor per cubic meter.

EXERCISES. 4. A lamp placed 3 feet from a screen gives an illumination equal to that of a standard candle placed at a distance of 1 ft. from the screen, lamp and candle being on opposite sides. Find the candle power of the lamp.

5. A gas jet and an electric lamp are placed on opposite sides of the screen so that the spot upon the latter is equally illuminated. The gas jet is 2 ft. from the screen; the electric light 6 ft. Compare the candle power of the two sources.

6. It is desired to find the candle power of a given arc light. It is found that when a standard candle is placed 1 ft. from the screen of the photometer, the latter has to be removed to a distance of 30 ft. from the arc light. Find the candle power of the arc.

ARTIFICIAL LIGHTING

330. Sources and Cost. Primitive man used torches, and in some cases crude lanterns holding swarms of fireflies, to guide him when he went forth at night. From that day to the present one of the problems which man has attempted to solve is the production of an illuminant in which a large

part of the energy supplied appears as light and a small part as heat. Thus far his attempts have been relatively feeble as compared with what nature has accomplished in the case of the firefly, Fig. 322, an insect which is capable of producing



FIG. 322.—The cold light produced by the firefly has challenged the best efforts of modern lamp experts

what is practically a cold light. Next in the order of artificial lights came the candle. This type of illuminant is still quite widely used, but ordinarily for decorative purposes where cost of light and illumination are not of primary consideration. Then came the kerosene lamp, a great improvement over the candle so far as illuminating power is concerned. Following the kerosene lamp we have the gas light, and finally the modern high power electric lamp.



The cost of lighting by any of the modern methods depends to a certain extent upon local conditions. For example, in some localities natural gas is available and is very cheap, and in others electric energy can be obtained at a very low cost.

The cost in any case depends upon the candlepower of the lamps used and upon the time they burn. In order then to make comparisons between kinds of lamps it is necessary to consider a definite amount of lighting, which may be obtained by multiplying the candlepower of the lamps used by the number of hours they burn. For example, 1000 candle-hours of lighting may be obtained by burning a 10-candle lamp 100 hours or a 50-candle lamp 20 hours, but if the lamps are of the same kind the cost will be about the same. Calculations of the cost of producing 1000 candle-hours by different lamps are sometimes useful in choosing between lamps, but of course it does not necessarily follow that the lamp for which the cost is lowest is most economical for household use. Data concerning relative costs of producing light by common methods usually employed in the house are given in Fig. 323. These costs are based on the following prices: Candles, 12 cents per pound; kerosene, 15 cents per gallon; gas, \$1 per 1000 cubic feet; electricity, 10 cents per kilowatt-hour. The solid lines represent cost of fuel or current, the shaded parts the cost of the materials and bulbs. Where prices are different from those given above, costs of course will be correspondingly different.

331. Illumination Furnished by Different Sources. *Candles.*

As a source of light candles are very expensive when one considers the cost per unit of lighting. It will be noted from Fig. 323 that the relative cost of 1000 candle-hours obtained from this source is \$2.

Oil lamps. Kerosene oil lamps are much more economical than candles, the cost for 1000 candle-hours being about 20 cents. That is to say, the cost of operating a kerosene lamp is about one tenth that of candle light, per unit of light furnished.

Gas lamps. The open gas flame is somewhat more expensive than the kerosene lamp, Fig. 323, being about 25 cents per 1000 candle-hours. The gas mantle lamp, however

furnishes one of the cheapest sources of light. The relative illuminating power of the open gas flame, upright mantle

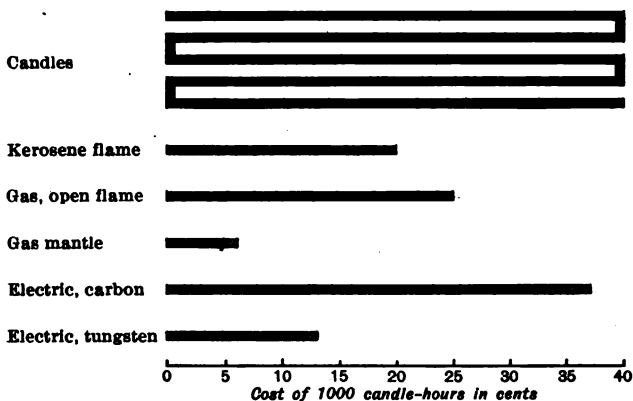


FIG. 323.—Relative cost of producing a given amount of light by various illuminants

gas lamp, and inverted mantle gas lamp is shown in Fig. 324, together with the distribution of the light in each case. Each lamp is supposed to burn 5 cubic feet per hour, costing one

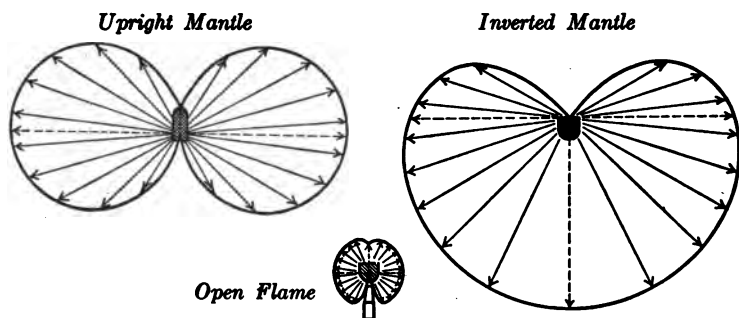


FIG. 324.—Comparison of the amount of light given by open flame, upright mantle, and inverted mantle gas lamps

half cent if gas is \$1 per 1000 cubic feet. Note that the mantle lamps give four or five times as much light as the open flame.

The inverted mantle gives more light downward and less upward than the upright mantle.

When city gas is supplied a definite candlepower is usually required by law. That is, when a given type of open flame burner is used burning 5 cubic feet of gas per hour the candlepower is specified. Thus for example, "20 candlepower gas" means 4 candlepower per cubic foot per hour in an open flame burner. At \$1 per 1000 cubic feet this is equivalent to 25 cents per 1000 candle-hours. If mantle lamps are used the efficiency depends on the quality of the lamp and the care which is taken to keep it in good condition. A good mantle lamp in fair condition should give 20 candlepower per cubic foot per hour; that is, the mantle lamp will give 5 times as much light per unit of cost as an open flame lamp. The cost of operating such a mantle gas lamp is about 5 cents per 1000 candle-hours.

The various methods of gas lighting which are used for country houses or small villages are in general more expensive than the gas or electricity available in larger towns. The cost of acetylene, for instance, is about 30 cents per 1000 candle-hours.

Electric lamps. Two kinds of electric lamps are common in household use. These are the ordinary carbon filament lamp, and the tungsten lamp. Both kinds are commonly marked with the number of watts (power) they take when used at the number of volts (electrical pressure) which is marked on the lamp. When electricity is paid for at a certain rate per kilowatt-hour (Art. 487) the cost of electrical energy for a lamp is easily calculated. The kilowatt-hour is 1000 watt-hours, and the number of watt-hours used by any electrical device is simply the watts times the number of hours burned. For example, a 50-watt lamp in 20 hours uses 1000 watt-hours or 1 kilowatt-hour; at ten cents per kilowatt-hour electricity for such a lamp costs one-half cent per hour. This is true of any 50-watt lamp without regard to the kind of

filament it has. The amounts of light produced, however, by different kinds of filaments are decidedly different, as illustrated

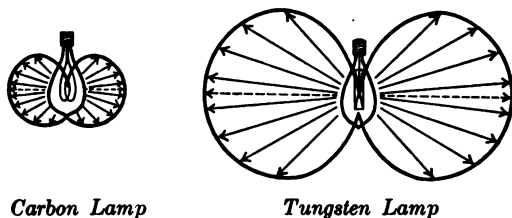


FIG. 325.—Comparison of amount of light furnished by a carbon lamp with that given by a tungsten lamp

in Fig. 325. For the same consumption of electrical energy a tungsten filament lamp gives about three times as much light as a carbon filament lamp. Or to put it another way, the cost for 1000 candle-hours is relatively as follows: Tungsten lamp, about 12 cents; carbon lamp, about 36 cents.

REFLECTION

332. The Law of Reflection. If a beam of light from a source *A*, Fig. 326, falls upon a polished surface it will be reflected to *C*. The line *BD* is drawn perpendicular to the surface of the mirror and is called a normal. The angle *ABD*, formed by the incident ray and the normal, is called the *angle of incidence*; the angle *DBC*, formed by the reflected ray and the normal, is the *angle of reflection*.

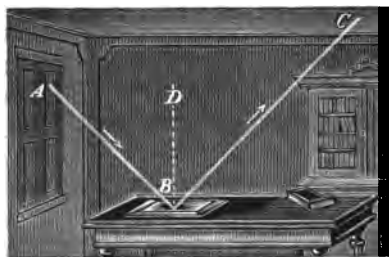


FIG. 326.—The angle of reflection is equal to the angle of incidence

The angle of incidence, *ABD*, is usually represented by the letter *i*, the angle of reflection, *DBC*, by the letter *r*.

The law of reflection: *The angle of reflection is equal to the angle of incidence, and both lie in the same plane.*

333. Mirrors and Images. A *mirror* is a polished surface capable of reflecting light. Images formed in mirrors are of two kinds, (a) virtual images and (b) real images.

(a) If a lighted candle be placed before a plane mirror a virtual image will be formed, which will appear to be as far back of the surface of the mirror as the object (candle) is in front of it. A *virtual image* is one which is due to the apparent

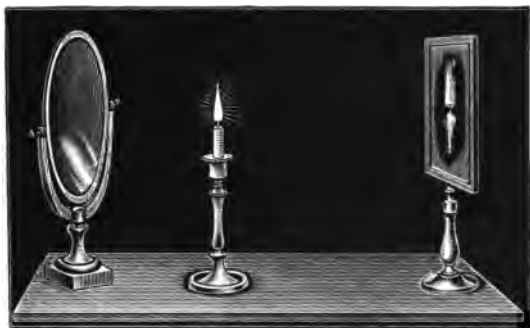


FIG. 327.—Formation of a real image by a spherical mirror

focusing of the rays of light; it appears to be where it really is not. All images formed in plane mirrors are virtual images. A virtual image appears to be behind the mirror only so long as there is an eye in front of the mirror to receive the reflected rays. When the observer withdraws the virtual image disappears.

(b) If now the candle be placed between the principal focus and the center of curvature of a spherical mirror (Art. 335) there appears on the screen a real image, as shown in Fig. 327. A *real image* is one which is formed by the actual focusing of the rays of light. The real image remains on the screen so long as the mirror and candle are in position. A real image may be photographed; a virtual image cannot be photographed.

334. Multiple Images. If an object such as a candle flame or a gas flame be held close to a plate glass mirror and viewed



FIG. 328.—Multiple images

at an angle, a series of images may be observed, Fig. 328, the second being the brightest one of the series. These are called multiple images, and their formation is explained by the fact that the light from the object is reflected from the mirror to the eye from both front and rear surfaces of the mirror. The first image which appears is due to the reflection from the surface of the glass. The second and brightest image is due to the reflection from the silvered covering on the rear surface of the mirror.

The other and fainter images are due to secondary reflections. It is because of the formation of multiple images that glass mirrors cannot be used successfully in certain kinds of scientific work, such as astronomical observations. For this purpose there are employed mirrors which are made of highly polished metal, and which, therefore, have but a single reflecting surface.

335. Images Formed by Plane Mirrors. Images formed by plane mirrors are virtual. A virtual image, as has been stated in article 333,

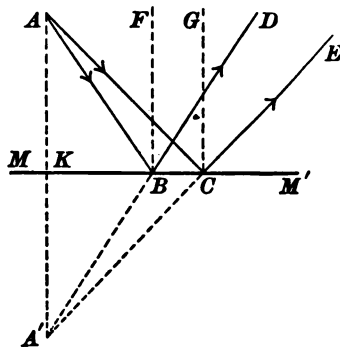


FIG. 329.—Plane mirror; virtual image at A'

is one formed by the apparent focusing of the rays of light from an object, Fig. 329. Suppose we have given an object

in front of a plane mirror to find the position and character of the image. Let A be an object in front of the mirror MM' . Draw from the point A two lines incident upon the mirror at B and C . Erect the normals BF and CG . Now draw the lines BD and CE in such a manner as to make the respective angles of reflection equal to their corresponding angles of incidence; that is, make angle $FBD = ABF$ and $GCE = ACG$. Now project the lines DB and EC until they meet, as at A' . An eye placed at DE so as to receive the rays BD and CE will see the virtual image at A' . The virtual image A' is as far back of the mirror as the object A is in front of it.

336. Spherical Mirrors. A *spherical mirror* is formed from a portion of a spherical shell. A section of a spherical mirror is shown in Fig. 330. The opening MM' is called the *aperture* of the mirror. A point midway between M and M' is the *vertex* V . The *center of curvature* of the mirror C is the center of the sphere of which the mirror is a part. A *principal axis* is a straight line passing through the center of curvature and the vertex. A *secondary axis* is any other straight line passing through the center of curvature and cutting the mirror at any point other than at V . The line CV is a principal axis; the line CS is a secondary axis. When we consider a spherical mirror from the concave side A , it is called a *concave mirror*; when we look at it from the convex side B it is called a *convex mirror*.

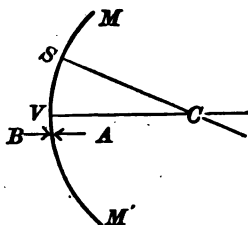


FIG. 330.—Spherical mirror

The *principal focus* of spherical mirrors is the point at which rays parallel to the principal axis come to a focus, Fig. 331. For *concave* mirrors this focus is *real* and a point, as may be shown by allowing the sun's rays, which are nearly parallel, to fall upon the mirror.

The principal focus of a *convex* mirror is a *virtual* focus and is the point at which rays parallel to the principal axis appear to come to a focus, Fig. 332.

337. Relation of Object to Image in Spherical Mirrors. The character (real or virtual), position, and size of an image

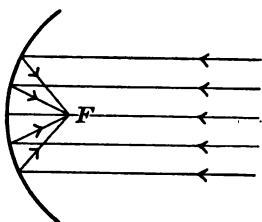


FIG. 331.—Concave mirror

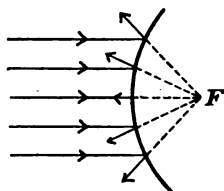


FIG. 332.—Convex mirror

formed by a spherical mirror depends upon the position of the object with respect to the mirror. And, further, the size, position, and character of the image may be determined in three ways, as follows: (a) By actual experiment; (b) by a graphical method, that is, by making a sketch in accordance with given conditions and (c) by means of mathematical

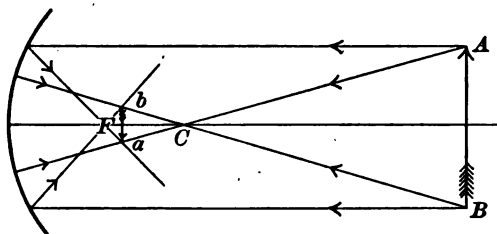


FIG. 333.—Object and image in spherical mirror

equations. There are four important cases to be considered. We shall illustrate these four cases by the graphical method.

Case 1. Given an object (a lighted candle, say) in front of a concave mirror and situated on the principal axis beyond the center of curvature (that is, at a distance from the vertex

of the mirror greater than the radius of the sphere of which the mirror is a part) to find the position and character of the image. Let AB , Fig. 333, be the object. Draw from A and B to the mirror two straight lines parallel to the principal axis. Since these rays are parallel to the principal axis, they, upon being reflected, pass through the principal focus F . Now from A and B draw lines through the center of curvature C . These rays fall upon the mirror normally (that is, forming right angles with the surface) and hence are reflected directly back upon themselves. Thus it appears that all lines from A come to a focus at a , and lines from B come to a focus at b , forming at this point a real image ab . Therefore, when the object is on the principal axis of a concave mirror, at a point beyond the center of curvature C , the image is real, inverted, smaller than the object, and lies between the principal focus F and the center of curvature C .

Case 2. Given an object on the principal axis of a concave mirror at a point between the principal focus F and the center of curvature C , to find the position and character of the image. This case is the converse of Case 1. Let the object be at ab . The direction of the rays are now reversed, and the image appears at AB . That is, the image is real, inverted, larger than the object, and is situated at a point on the principal axis beyond the center of curvature.

Case 3. Given an object on the principal axis of a concave mirror at a point between the principal focus and the vertex V , to find the position and character of the image. Let AB , Fig. 334, be the object. Draw from the points A and B to the mirror lines parallel to the principal axis; these rays are reflected back through the principal focus F . Next draw from A and B lines normal to the surface of the mirror; these rays are reflected back through the center of curvature C . It will be observed that the respective rays from A and B are divergent, hence they will never come to a focus on the right side of the mirror, as shown in Fig. 334. No real image

will therefore be formed. If, however, an eye be placed in such a position as to receive these divergent rays a virtual

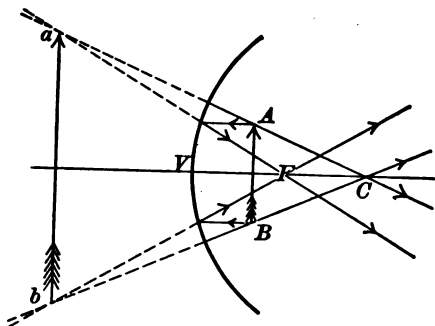


FIG. 334.—Virtual image formed by concave mirror

image will appear at ab . Thus, in this case, the image is virtual, erect, larger than the object, and on the opposite side of the mirror from the object. In other words we have a

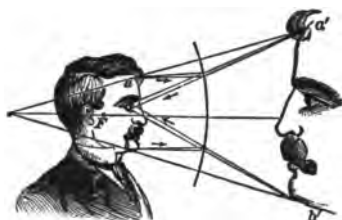


FIG. 335.—Virtual magnified image as seen in a small concave shaving mirror

magnified, virtual image. In Fig. 335 there is shown a magnified virtual image of a man's face as seen in a small concave mirror, such as is occasionally used for shaving purposes.

Case 4. Given an object AB on the principal axis of a convex mirror, Fig. 336, to find the position and character of the image. Drawing lines from A and B as before (that is, one set parallel to the principal axis and the other set as passing through the center of curvature C , we find that the reflected rays are divergent. Projecting these lines on the opposite side of the mirror gives the location of the virtual image at ab . In this case the image is virtual, erect, smaller than the object, and located on the opposite side of the mirror.

A consideration of the four cases described in the foregoing reveals the facts that (a) in cases 1 and 2, the images are *real*, (b) in cases 3 and 4 the images are *virtual*, and (c) the size of the image in any given case depends upon the relative position of the object with respect to the mirror. The reason for drawing at least two rays from each point in the object, as from *A*, is because at least two rays are always required to determine a focus. Of course as many other rays may be drawn from *A* to the mirror as desired; these, however, would all come to a focus at the point *a*, and would only serve to confuse the figure.

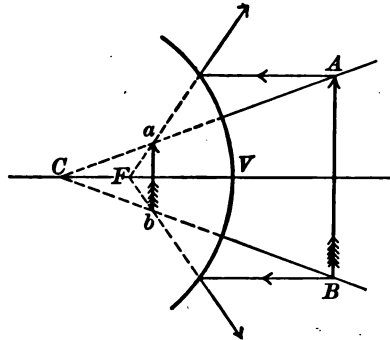


FIG. 336.—Virtual image formed by convex mirror

338. Spherical Aberration. In the preceding cases of the spherical mirror, it has been taken for granted that all rays parallel to the principal axis after being reflected pass through the principal focus. This, however, is not true for those rays which fall upon the mirror near the extremities *M* and *M'*; the reflected rays for this portion of the mirror do not pass through the principal focus. This failure of part of the light to pass through the principal focus is called *spherical aberration*.

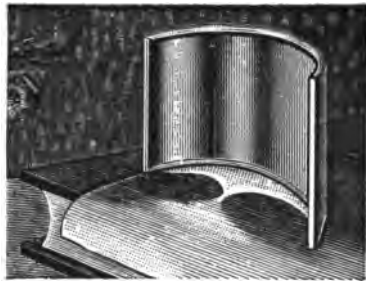


FIG. 337.—Caustic due to spherical aberration of light

Spherical aberration in the case of circular reflecting surface gives rise to a curved line of light called the *caustic*. A caustic

curve can be demonstrated experimentally by allowing rays of light to fall upon the concave surface of a strip of polished metal (bright tin) bent in the form of a circular arc, Fig. 337, the reflected light being received on a piece of white paper upon which the strip of metal rests. This same effect may be seen by allowing the sunlight to fall upon the inside of a gold finger ring placed upon a piece of white paper.

REFLECTORS AND ILLUMINATION

339. Diffused Light. If a beam of light falls upon a smooth surface it will be regularly reflected, as shown in Fig. 338. If this light be received by the eye, the latter will see not the reflecting surface, but the source of light. For example, light reflected from the surface of highly polished furniture, or the surface of still water, shows this property.

If, on the other hand, a beam of light falls upon a body having an irregular surface, such as a piece of white paper or the wall of a room, the light is scattered in all directions, Fig. 339. This is called diffused light. It must not be imagined, however, that diffused light does not obey the laws of reflection, for it

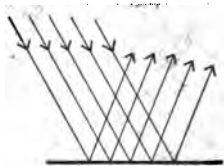


FIG. 338

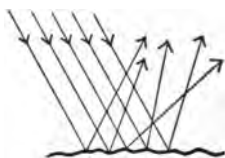


FIG. 339

Regular and diffused reflections

does, the angle of reflection for each ray in every case being equal to the angle of incidence. The scattering of the rays is due to the irregularities in the reflecting surface. It is by means of this diffused light that we are enabled to see clearly the outline of bodies. If every object possessed a polished surface we would see only the light of the source and would

not be able to make out clearly and definitely the outline and nature of the reflecting surface.

340. Distribution of Light. The proper distribution of light with reference to the most satisfactory illumination depends in a large measure upon the kind of shade or reflector used. There are three methods of distribution which are used with lighting systems. These are (a) the direct method, (b) the indirect method, and (c) the semi-direct method.

The *direct method* is one in which the light shines directly from the source upon the area illuminated. This method gives the maximum amount of light for a given expenditure of energy; it is in general objectionable, however, because of the glare which comes from the lamp or from polished surfaces upon which the light falls.

The *indirect method* is one in which the light is placed within bowl-like reflectors near the ceiling. The light is thrown upward upon the ceiling and is thence reflected as diffused light throughout the room. The indirect system of lighting gives less illumination per unit of light at the source than that furnished by the direct system; it, however, avoids the glare of the direct light, and in addition it gives a soft and pleasing lighting effect throughout the room. A ceiling reflector for the production of indirect diffused illumination is shown in Fig. 340.



FIG. 340.—Reflecting bowl for indirect lighting

The *semi-direct method* is designed to combine the advantages of both the direct and the indirect systems by reflecting part of the light directly upon a limited area and part to the ceiling, from which it is reflected diffusely. In this method of illumination that portion of the light which is intended

to fall upon a given area, as upon a table or desk, is frequently transmitted through a translucent screen or shade.

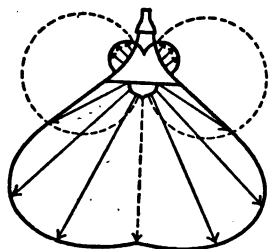


FIG. 341.—Distribution of light by a reflecting shade

A diagram of the distribution of light from a tungsten electric lamp provided with opal glass reflector is shown in Fig. 341. The curved dotted lines on each side of the lamp represent the distribution of the light when the reflecting shade is removed; the heavy lines below the lamp represent the distribution due to the reflector.

With regard to the relative efficiency of direct, indirect, and semi-indirect systems of lighting there has been much argument. There can be no doubt that every time light is reflected or is transmitted through a diffusing medium part of the light is lost. In a properly planned direct-lighting equipment most of the light is reflected only once or not at all before reaching the place where it is used. In indirect lighting the light undergoes at least one additional reflection (at the ceiling), causing a loss which can hardly be less than 25 per cent, and it may be much more. The diffusing shades used in so-called semi-direct lighting throw a large part of the light to the ceiling, where it suffers a similar loss, while that part of the light which goes through the bowl is reduced considerably by absorption. Consequently, if we measure the efficiency of lighting by the fraction of the light which is finally thrown down upon the objects in the room, well-planned direct lighting will always be found to be the most efficient. This advantage is accentuated if it is desired to light a particular area, for direct lighting fixtures give most exact control of the distribution of the light, the other methods unavoidably giving a rather widely scattered light.

However, the quantity of light falling upon a given area is not the only thing which determines whether or not one can

see well. The proper diffusion of the light, the illumination of the surroundings, and the protection of the eye from excessive brightness are all of great importance, and in these respects a direct-lighting fixture is more likely than the other types to be faulty. Hence it often happens that a poor direct lighting equipment can be replaced by an indirect, or semi-indirect one, giving a better illumination with no greater consumption of power.

341. Rules to be Observed in Reading or Working by Artificial Light. 1. *Do not work with a flickering light.* In such a light the eye is constantly being called upon to readjust itself, and is never properly adapted for the light it receives at any particular instant. Severe fatigue is the result.

2. *Do not use unshaded lamps.* The bare flame, mantle, or filament is injuriously bright, and without shades one's glance is certain to fall upon the dazzling lamp more or less frequently. Moreover, diffused light, that is light from a considerable surface, usually gives more effective illumination than that from a small source.

3. *Do not judge of illumination by looking at the lamp.* The lamp is not meant chiefly to be seen but rather to enable you to see other things. The lamp which itself looks most brilliant may be for that very reason least effective. The light that comes directly from the lamp to the eye does no good and may interfere very seriously with the useful light which has gone from the lamp to surrounding objects and thence to the eye.

4. *Do not face the light.* The old rule that light should come from above and over the left shoulder is good. With the lamp so placed there is little likelihood of getting the brilliant reflection from table tops, smooth paper, or other shiny material which is so detrimental to good seeing; there is also little chance of letting the eyes fall upon the lamp itself. The common arrangements of lamps on library tables where the reader faces the lamp, while his book lies on the table, is very bad, unless the lamps are heavily shaded and the book lies at

such a slope that the light regularly reflected from the page falls far away from the reader's eyes.

5. *Do not put the lamp too close to your work.* This gives an excessive contrast between the work and the surrounding objects, and the eye does not adapt itself properly to the intensity of light on the work. In factories it has been found that if lamps are removed from individual machines and hung high enough to give a good illumination over the machines and their surroundings much better work can be done, and the total amount of light needed is often no greater. Similarly, tests have shown that when a desk lamp is used in a room otherwise unlighted the average person needs much more light to read on the desk than he does when the light is furnished by lamps which at the same time illuminate the whole room moderately.

A special reading lamp, or other lamp for local lighting, is often useful, but it is best used in connection with a soft general lighting.

REFRACTION OF LIGHT

342. Introductory. Place a coin on the bottom of an empty cup so that it lies just inside the range of vision as bounded by



FIG. 342
Refraction of light

the side of the vessel. Now pour water carefully into the cup until it is full; the coin comes gradually into view as the surface of the water rises. This is due to the fact that rays of light from the coin to the eye are bent at the surface of the water, as shown in Fig. 342. The eye in looking along the line appears to see the coin in an elevated position. In like manner

when we look vertically downward at the bottom of the vessel filled with water the apparent distance from the surface to the bottom is less than the real depth; indeed the bottom appears to be in a position about three-fourths of the real depth.

Again if a stick be placed in a slanting position in water, it appears to be bent at the surface, due to the bending of the rays of light in their passage from the relatively dense water to the rare air. This apparent bending at the surface may be beautifully demonstrated by observing a spoon placed in a tumbler which is partly filled with water, Fig. 343.

The bending of the rays of light (refraction) accounts for the apparent displacement of stars and other heavenly bodies,



FIG. 343
An illustration of refraction

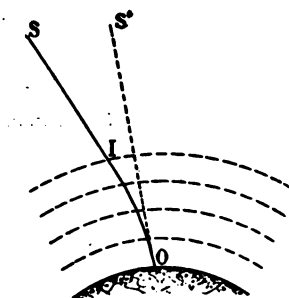


FIG. 344
Refraction due to the passage of light through layers of air of different densities

Fig. 344. The ray of light from the star S is bent (refracted) as it passes through successive layers of the atmosphere so that an observer on the surface of the earth at O sees the star as if it were at S' . The apparent position of the star is higher than the real position. It thus frequently happens that the sun is visible while yet actually below the horizon.

The mirage is a phenomenon frequently observed in deserts, in which the traveler sees the image of distant objects, such as palm trees, etc., usually by refraction. The explanation of

the mirage lies mainly in the fact of the refraction of light through layers of air of different density. A phenomenon

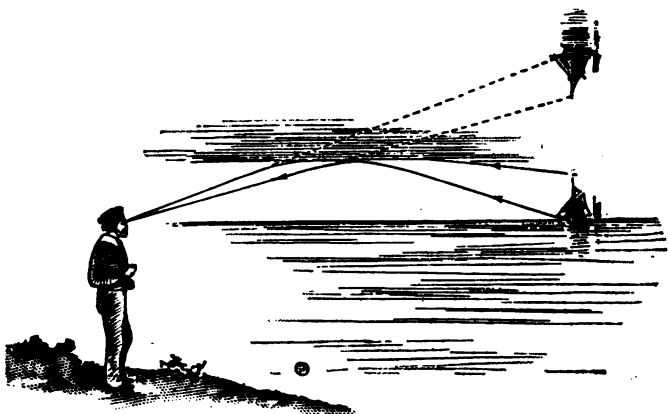


FIG. 345.—Mirage due to refraction

somewhat similar to the mirage of the desert is occasionally seen at sea in still, hot weather, in which the image of a distant

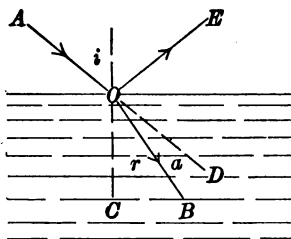


FIG. 346
Reflection and refraction of light
at the surface of water

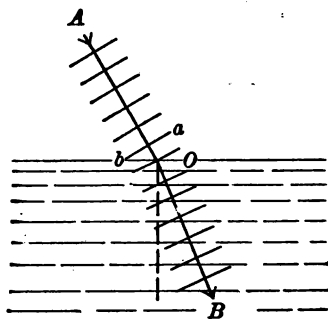


FIG. 347
Explanation of refraction

ship appears in the sky, sometimes upright, sometimes inverted, as shown in Fig. 345.

343. Refraction. If a beam of light be allowed to fall upon the surface of water at O , Fig. 346, a part will be reflected to E , according to the laws of reflection, and a part will be refracted to B . *Refraction* is the bending of a ray of light due to passing from a medium of one density to that of another density. The angle i is the angle of incidence, the angle r is the angle of refraction, and a is the angle of deviation.

An explanation of refraction may be given somewhat as follows: Imagine a series of wave fronts advancing in the direction AO , Fig. 347. When the portion of the wave marked b strikes the surface of the water its speed is retarded; a , therefore, moves faster than b , hence the wave front is bent downward, as shown, and the direction of the motion is changed from AO to OB . After a wave once passes into a medium both portions of the wave front, a and b , move forward with the

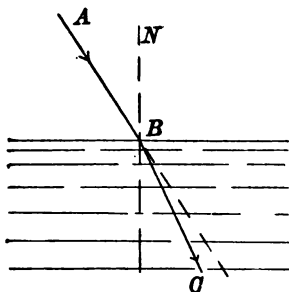


FIG. 348
Light passing from air to water
is refracted toward the normal N

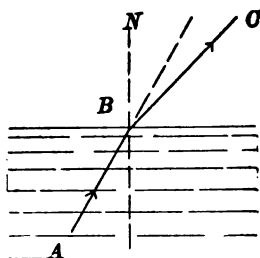


FIG. 349
Light passing from water to air
is refracted away from the
normal N

same speed; therefore the line of direction OB is a straight line. Refraction of light is due to a change in the speed of one portion of a wave front as it passes from one medium to another medium of different density.

These facts should be carefully noted by the student: (a) A beam of light passing from a medium of given density (as air) to a medium of greater density (water) is refracted *toward* the

normal N , Fig. 348; (b) light passing from a dense medium to less dense medium is refracted *away* from the normal N , Fig. 349.

344. Critical Angle. Consider a source of light at A in the medium water, Fig. 350. A ray from A to B will be refracted away from the normal to C . For this ray the angle of incidence is ABN' and the angle of refraction CBN . A ray of light from E to B will be refracted along the surface of the water to D . In this case the angle of incidence is EBN' and the

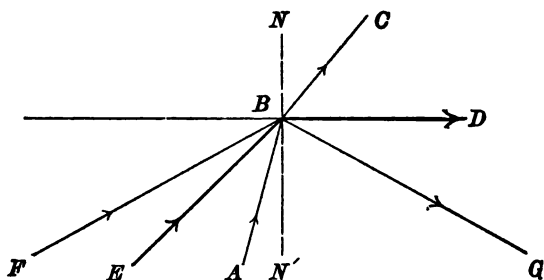


FIG. 350.—Critical angle, EBN'

angle of refraction $DBN = 90^\circ$. The angle EBN' is called the critical angle. The *critical angle* is an angle of incidence such that the angle of refraction is 90° . When we speak of a critical angle we always think of the light as passing from a relatively dense to a less dense medium, as from water or glass to air.

When the angle of incidence of a ray of light passing from a dense to a rare medium is greater than the critical angle, we have total internal reflection. The smaller the critical angle of a given substance the greater is the total internal reflection. The diamond, for example, has a small critical angle, and therefore, most of the light falling upon the surface from the interior suffers total internal reflection. The large proportion of light which is totally reflected in the diamond gives rise to the great brilliancy of this gem.

A beautiful illustration of total reflection is furnished by a stream of water flowing from a tank, Fig. 351, having in the side opposite the orifice a lens by means of which a strong beam of light from the sun or an electric arc may be concentrated within the jet. The light strikes the interior surface of the stream of water at an angle greater than the critical angle and thus suffers total internal reflection. The light is held within the stream until, after repeated reflection, it strikes the bottom of the receptacle, where it shows a bright spot. A goblet held in the stream is filled with bright light, which gives rise to the name "fountain of fire." The brilliant display seen in electric fountains depends upon this principle.

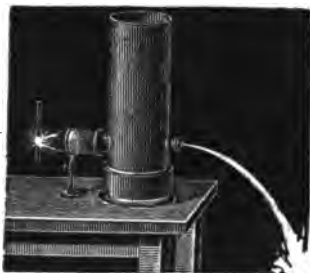


FIG. 351.—The "fountain of fire"

345. Passage of Light through Different Media. *Parallel plate.* Let a ray of light AB , Fig. 352, be incident upon the

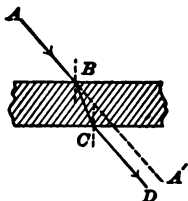


FIG. 352
Refraction through a parallel plate and through a prism

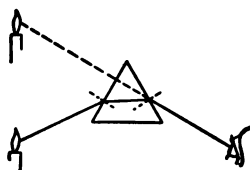


FIG. 353

surface of a piece of plate glass at the point B . Let BD represent the refracted ray. At B the ray is bent toward the normal as it passes into the denser medium, and at C is bent away from the normal as it passes out. The refraction at C is equal to that at B and in the opposite direction. The

ray CD is therefore parallel to AB . When a ray passes through a plate having parallel faces its direction is unchanged; it suffers only lateral displacement.

Prism. Let a ray of light fall upon a prism, Fig. 353. On entering the prism the light is bent toward the normal and on emerging it is bent away from the normal, both refractions being toward the base of the prism, as shown. An eye will appear to see the object (candle) as if it were elevated in line with the final refracted ray.

346. Index of Refraction. *The index of refraction* of a medium is the ratio of the velocity of light in air to the velocity of light in the given substance. For example, the ratio of the velocity of light in air is to that in water as 4 to 3; that is, light travels $4/3$ as fast in air as in water. The index of refraction of water is therefore $4/3 = 1.33$.

There are several methods of determining the index of refraction for any given substance. One of the simplest (though not the most accurate) is by means of the refraction tank, Fig. 358. A refraction tank is a rectangular glass

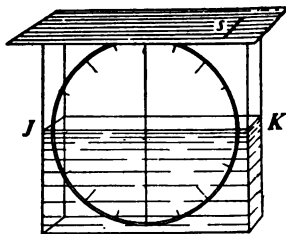


FIG. 354
Refraction tank for demonstration of index of refraction

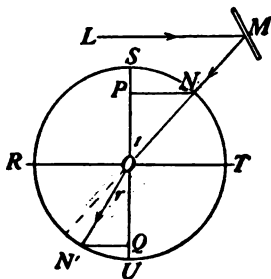


FIG. 355

vessel which is half filled with water, and one face of which is provided with a graduated circle. Over the top of the tank there is placed an opaque screen, having a slit S for the admission of a beam of light. A beam of light L , Fig. 355, is re-

flected from a mirror m into the tank at N . This beam of light, MN , falls upon the surface of the water at O , and is refracted to N' . Draw the lines NP and $N'Q$ perpendicular to the vertical line SU . Now it may be shown mathematically that the velocity of light in the air is to that in the water as line PN is to line QN' , both of which may be measured. It may be shown experimentally that for water with respect to air

$$\frac{PN}{QN'} = \frac{4}{3} = 1.33$$

TABLE XXII

INDICES OF REFRACTION

Alcohol.....	1.36	Diamond.....	2.47
Canada Balsam...	1.50	Flint glass.....	1.62
Carbon disulphide.	1.64	Ice.....	1.31
Crown glass.....	1.52	Water.....	1.33

347. Kinds of Lenses. A *lens* is a transparent medium bounded in general, by two spherical surfaces, or one spherical and one plane surface. Lenses are of two general classes, convex and concave.

A *convex lens* is one that is thicker in the middle than at the edges. Convex lenses are divided into three sub-classes,



FIG. 356
Convex lenses



FIG. 357
Concave lenses

as shown in Fig. 356, double-convex, plano-convex, and concave-convex. It is important to note that each one of these sub-classes conforms to the requirement of the convex lens; namely, it is thicker in the middle than at the edge.

A *concave lens* is one which is thinner at the middle than at the edge. Concave lenses are likewise divided into three sub-classes, Fig. 357, double-concave, plano-concave, convex-concave.

Since a lens is made up of the intersection of two spheres, or of one sphere and a plane, we may speak of the *center of*

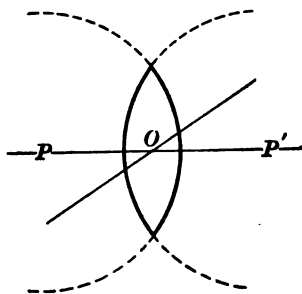


FIG. 358.—Principal axis and optical center of a lens

curvature of the lens as the center of the sphere of which it is a part. Since a lens always has two faces, it therefore always has two centers of curvature. A straight line PP' , drawn through the centers of curvature of a lens, is called the *principal axis*, Fig. 368. The *optical center* of the lens O is a point through which a ray may pass without having its direction changed. In double-convex and

double-concave lenses, having surfaces of equal curvatures, the optical center is at the center of the lens. In some cases the optical center may not lie at the geometrical center, as illustrated by plano-concave, or plano-convex lenses. The *principal focus* of a lens is the point on the principal axis PP' at which rays parallel to the principal axis come to a focus, Fig. 359. The *focal length* of a lens is the distance measured on the principal axis from the optical center O to the principal focus F .

348. The Effect of Lenses on Parallel Rays. The effect of a lens in changing the direction of a ray of light is exactly similar to that of a prism; indeed, every section of a lens may be considered as a prism. Rays of light parallel to the principal axis are therefore bent toward the normal on entering the lens and away from the normal on leaving it. The general effect of lenses may be stated as follows: (a) *Convex lenses are convergent*; that is, they cause the rays of

light to come to a focus, Fig. 359. (b) *Concave lenses are divergent*, Fig. 360.

The focus of a convex lens is real and lies on the opposite side from the object, Fig. 359. The focus of a concave lens is virtual and lies on the same side as the object, Fig. 360.

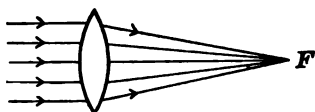


FIG. 359
Convex lens, convergent,
with real focus

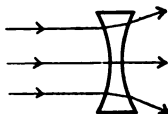


FIG. 360
Concave lens, divergent,
with virtual focus

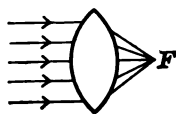


FIG. 361
The thicker the
lens the shorter
the focal length

The focal length of a lens depends upon its index of refraction and upon its curvature. In general, the less the curvature of the lens (that is, the flatter the lens) the greater the



FIG. 362.—Real image formed by convex lens

focal length; and on the other hand the greater the curvature the less the focal length (compare Fig. 359 with Fig. 361).

349. Illustration of Images Formed by Lenses. (a) Place a candle some distance from a screen in a darkened room. Next place a convex lens between the candle and the screen, and

relatively near the candle. Adjust the position of the lens until a clear image of the candle is thrown upon the screen, Fig. 362. The image is real, inverted, and larger than the candle. Now change the position of the lens, keeping it between the candle and the screen, but relatively near the screen. A second position will be found at which an image again appears upon the screen. In this case the image is real, inverted, and much smaller than the object.

Thus, as in the case of the mirror, the size of the image formed by a lens depends upon its position with respect to the object and the screen.

350. Relation of Object to Image. We have here three general cases to deal with, namely, (a) object beyond the principal focus F , of a convex lens, (b) object between F and the convex lens, and (c) images formed by concave lenses. We wish to find the position and character of the image in each case by the graphical method.

Case 1. Given an object AB on the principal axis of a convex lens and located at a distance from the lens greater than the focal length, Fig. 363, to find the position and char-

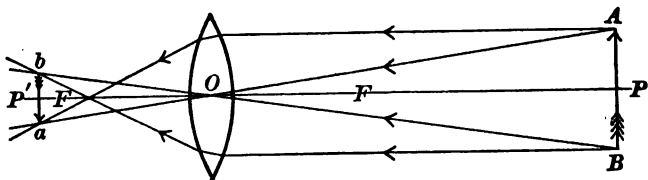


FIG. 363.—Real image formed by convex lens

acter of the image. Now in order to determine the position and character of the image, it is necessary to draw at least two rays from each of the points A and B of the object to the lens. We select, with reference to each point, two rays the direction of which can readily be determined; with reference to A , say, these are respectively a ray parallel to the principal axis, which after reflection passes through the principal focus

F in the direction Fa , and the ray Aa passing through the optical center. In a like manner we draw from the point B two similar rays, one passing through the principal focus and the other passing through the optical center. Thus we

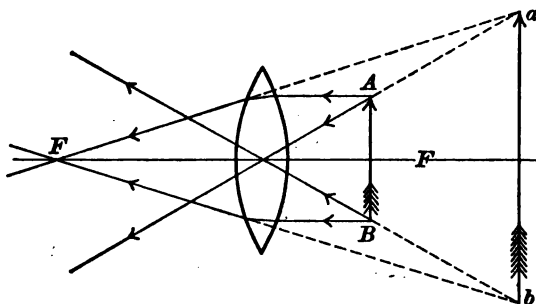


FIG. 364.—Virtual image formed by convex lens

have formed at ab a graphic representation of the image. It is real, inverted, and is located beyond the principal focus F , on the side of the lens opposite to that of the object AB . The size of the image ab depends upon the position of the object AB .

Case 2. Given an object AB between F and the lens, Fig. 364, to find the position and character of the image. The rays from AB on the right side of the lens are divergent, hence no real image is formed. If, however, an eye be in a position on the left side of the lens to receive the divergent rays, a magnified virtual image will be seen at ab . The image in this case is virtual, erect, and larger than the object. This is the case of the simple microscope (Art. 352).

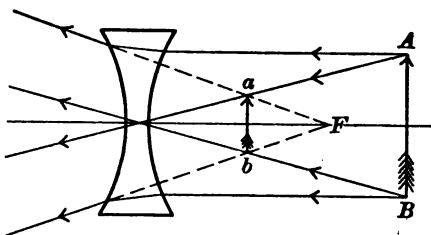


FIG. 365.—Virtual image formed by concave lens

Case 3. Given an object AB on the principal axis of a concave lens, Fig. 365, to find the position and character of the image. The image is virtual, erect, smaller than the object, and located between the principal focus F and the lens.

351. Spherical Aberration in Lenses. In the preceding topics it has been assumed for the sake of simplicity that all rays which pass through the lens also pass through the principal focus.

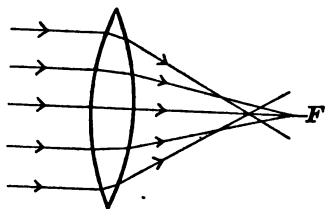


FIG. 366.—Spherical aberration in a lens

This, however, is not the case. In thick convex lenses those rays which pass through near the edge of the lens cross the principal axis nearer the lens than do those rays which pass through near the principal axis, Fig. 366.

This failure of all the rays to pass through a common point produces a blurring of the image. *Spherical aberration* is the failure of the marginal rays to pass through the principal focus.

Spherical aberration in a lens may be remedied by cutting off the marginal rays by means of a screen or diaphragm. The use of a diaphragm makes the image sharper in outline, but less bright. In large lenses, such as are used in telescopes, spherical aberration is diminished by making the curvature of the lens less toward the edge, thus tending to bring all parallel rays to the same focus.

OPTICAL INSTRUMENTS

352. The Simple Microscope. The *simple microscope* or common magnifier, such as is used in examining botanical and zoological specimens and other small objects, Fig. 367, illustrates Case 2 of the common lens (Art. 350) in which the object is placed between the lens and the principal focus. The image is virtual, magnified, and erect.

The supporting legs of the instrument must be short enough so that an object placed on the table or desk upon which they rest lies between the principal focus and the lens.

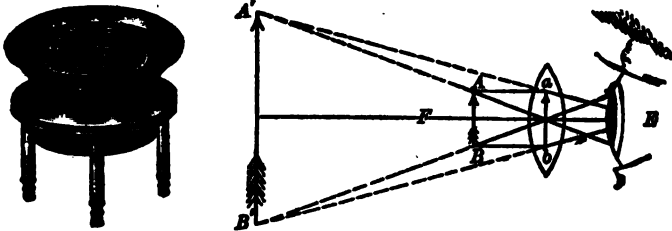


FIG. 367.—Simple microscope

363. The Compound Microscope. The *compound microscope* is a relatively high-power magnifying instrument, Fig. 368, having two systems of lenses. The lower lens system which is near the object to be examined is called the objective, and the upper system is the eye piece.

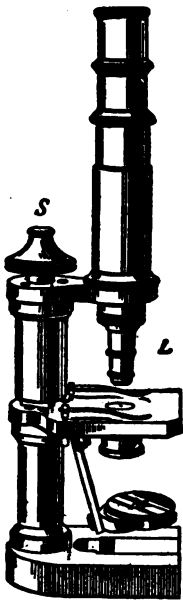


FIG. 368
Compound microscope

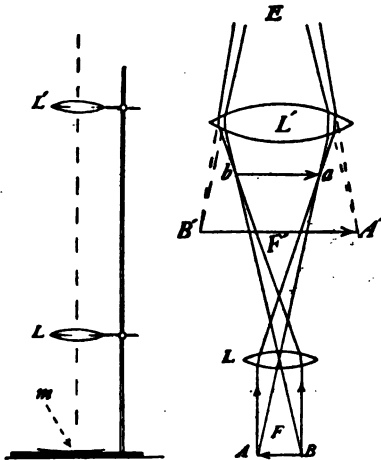


FIG. 369
Demonstration compound microscope

A compound microscope suitable for laboratory purposes may readily be constructed by mounting two convex lenses on a standard, as shown in Fig. 369. The objective lens L should have a focal length of about 5 centimeters; the eye-piece lens L' , a focal length of about 25 centimeters. Place the lenses in position on the support, the lens having the short focal length being at L . Place a card bearing printed matter or a small pencil mark upon it below the lens, at m . Lower lens L until the object (mark on the card) lies just a little outside of the principal focus. Now move lens L' up and down until a position is found such that a clear and magnified image of the object is seen when looking vertically downward along the dotted line.

A study of the outline sketch accompanying Fig. 369 will make clear the relative positions of object and images in the compound microscope. Let AB represent the object (mark on the card). Note that the object AB lies outside the principal focus F of lens L . The image ab is real, and lies between the principal focus F' and the lens L' . That is to say, in order to adjust the lenses so as to form a compound microscope it

is necessary to set them with reference to each other so that the conditions shown in the outline in Fig. 373 hold. An eye at E sees a magnified virtual image at $A'B'$. Note that the virtual image $A'B'$ is inverted with respect to the object AB .

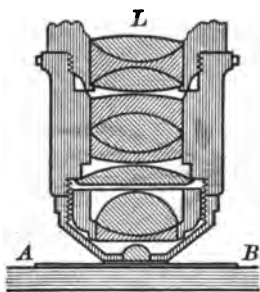


FIG. 370
Compound objective of a
high-power microscope

In some high-power microscopes the objective lens system may consist of a combination of as many as ten lenses, as shown in Fig. 370.

354. The Telescope. A *telescope* is an instrument for viewing distant objects, such as stars or bodies on the earth at a relatively great distance. The function of a telescope is not so much

to magnify a distant object as to bring it into clear view. One difference in construction between the telescope and the compound microscope is in the relative size of the objective lenses used. In the telescope the objective lens is relatively large; in the microscope the objective lens is small. The object of making the objective lens large is for the purpose of collecting within the instrument as much light as possible so as to admit of the required magnification without too much loss in brightness. In the Yerkes telescope, Yerkes Observatory, University of Chicago, which is the largest refracting telescope in the world, the objective lens is 40 inches in diameter. This great lens is mounted in a tube 63 feet in length.

The principle of the telescope may be demonstrated in the laboratory by mounting two lenses, as shown in Fig. 371.

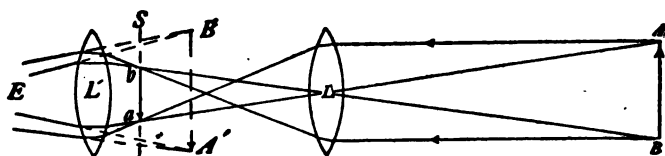


FIG. 371.—Lens system of telescope

The focal length of L , the objective lens, should be about 50 centimeters, and that of L' about 10 centimeters. Let the object AB be a candle or better an electric light. Mount lens L and find the position of the real image ab by means of a paper screen S . Now mount lens L' in such a position that the image ab lies between lens L' and its principal focus. An eye at E will see a virtual, magnified image of AB at $A'B'$.

355. The Binocular Glass. A *binocular field glass*, Fig. 372, is a short compact telescope having a system of lenses for each eye. The arrangement of the objective and eyepiece is practically the same as in the astronomical telescope. The necessary distance between the objective lens and the eyepiece, however, is obtained by having the light travel the length of the tube three times in passing from the objective to

the eyepiece. This is accomplished by reflection by means of a system of prisms within the tube of the instrument. The light from the object enters at *D* and after four reflections in each tube emerges through the eyepiece at *E*.

356. The Stereoscope. Nearly every child in school nowadays is familiar with the *stereoscope*, Fig. 373, an instrument for viewing photographs, which are mounted in pairs, and which are held in place in a receiving frame. The function of the stereoscope is first to give a single slightly magnified image of

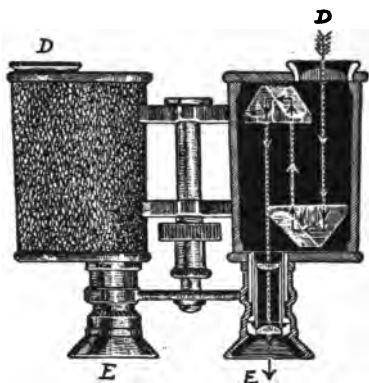


FIG. 372.—Binocular field glass

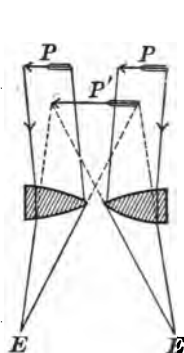


FIG. 373
Stereoscope

the object, and second, and primarily, to give an image the characteristic appearance of depth as well as area.

When an object is seen with both eyes the image formed on the two retinas differ slightly, because of the fact that the two eyes are viewing the object from slightly different angles. It is this difference in the two images which gives a landscape viewed with two eyes the appearance of depth, or solidity, which is absent when one eye is closed. The stereoscope reproduces in photographs this effect of binocular two-eyed vision. In preparing stereographic photographs, or *stereographs*, two photographs of an object, such as a landscape, are taken at different angles. These photographs are then

mounted on a card side by side. When these photographs are viewed simultaneously with both eyes through the lenses of the stereoscope a single slightly magnified image is seen which presents the same characteristic appearance of depth as when viewed under normal conditions with both eyes.

357. The Periscope. A *periscope* is a jointed telescope which possesses two or more reflecting surfaces, and which enables one in a trench or in a submarine to see around a corner or over an intervening object. The principle of the

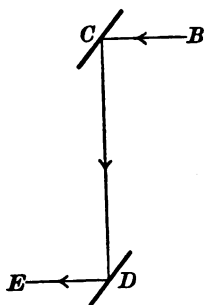


FIG. 374

The periscope and field of view



FIG. 375

periscope may be illustrated in a very simple way by mounting two mirrors, as shown in Fig. 374. Light from *B* is reflected at *C* and *D* to the eye at *E*. The type of periscope which is used on submarines contains a system of lenses which gives a magnification of about one and one-half diameters, this being the magnification necessary to make ships appear at their true distance from their observer.

In Fig. 375, there is shown the field of vision as seen through the periscope of a submarine.

358. The Projection Lantern. The *projection lantern*, Fig. 376, is a device for throwing upon a screen an enlarged image of an object such as pictures on a lantern slide. The projection device consists essentially of two optical systems, one

called the condenser lens C , the function of which is to condense the divergent rays from the electric light L upon the slide S ; the other is the objective lens O , the function of which is to focus the light upon the screen. The image is real and inverted.

The distance of the slide S from the objective lens O is called the object distance, and the distance of the image on the screen from objective lens O is called the image distance.

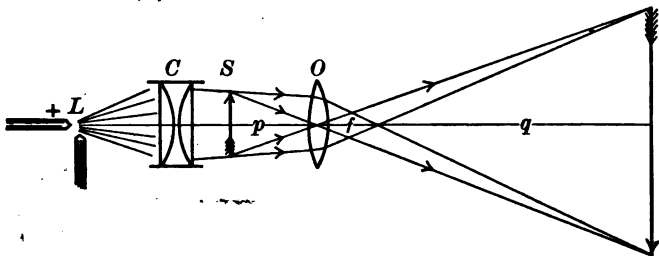


FIG. 376.—Section of projection lantern

In order to focus the lantern so as to bring out clearly the picture upon the screen, the lens O is moved back and forth until a sharp image is produced. The electric arc is almost universally used as the source of light for projection purposes, although other sources may be employed, such as the acetylene light. The carbons forming the arc are adjusted to touch at right angles. The upper carbon is positive in the case of a direct current, thus throwing the brilliant light from the incandescent crater directly into the condensing lens.

359. The Eye. We have in the case of the human eye a very remarkable application of the principle of the formation of real images by a convex lens. The characteristic parts of the eye are shown in Fig. 377. The outer portion of the eyeball s consists of a tough covering called the sclerotic coat; b is the choroid coat, containing a black pigment, the function of which is to prevent internal reflection of the light; r is the retina, formed by an expansion of the optic nerve;

covering the front of the eye is the cornea *c*, a transparent medium; *i* is the iris, which gives the eye its characteristic color and the function of which is to regulate the quantity of light entering through the pupil *p*. The three refracting

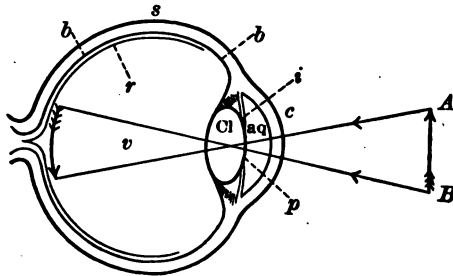


FIG. 377.—Section of human eye

media are *aq*, the aqueous humor; *cl*, the crystalline lens; and *v*, the vitreous humor. The most important of the three, from an optical viewpoint, is the crystalline lens.

The image formed upon the retina by an object situated in front of the eye is real, smaller than the object, and inverted. If a candle be held in front of an eye taken from a freshly killed animal, it is possible under satisfactory conditions to



FIG. 378.—Image formed on retina, as seen in the eye of a recently killed ox

see the inverted image formed upon the retina, as shown in Fig. 378. The question naturally arises as to why it is that we can see objects erect when the image upon the retina is inverted. The explanation probably lies in the fact that our

judgments of the true position of bodies with respect to each other is based primarily upon experiences other than those of sight. It is said that the blind upon recovering sight often find it necessary at first to use the sense of touch in determining the true position of bodies.

In using the camera it is necessary to focus the instrument by moving either the screen or the lens back and forth so as to bring the image upon the plate. In the case of the eye, however, this focusing is accomplished automatically by changing the convexity of the crystalline lens. It is very remarkable that we can involuntarily and almost instantly change the shape of the crystalline lens so that the image of an object only a few inches distant, or an object miles away, may be distinctly focused upon the retina.

360. The Abnormal Eye. The three most common defects of the eye are: (a) nearsightedness, (b) farsightedness, (c) astigmatism.

In the normal eye light from a given object is focused exactly upon the retina. The *nearsighted eye* is one in which the rays

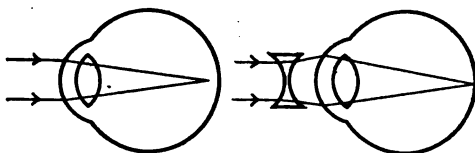


FIG. 379

FIG. 380

Nearsighted eye, and correction by use of concave glasses

from the crystalline lens come to a focus before reaching the retina, Fig. 379. Persons having such eyes are said to be nearsighted, because they have to bring the object very near the eye in order to see it distinctly. Nearsightedness is remedied by the use of concave glasses, which diverge the rays and thus throw the image farther back upon the retina, Fig. 380.

The *farsighted eye* is one in which the image tends to form beyond the retina, Fig. 381. The remedy for farsightedness lies in the use of convex glasses, Fig. 382.

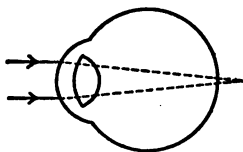


FIG. 381

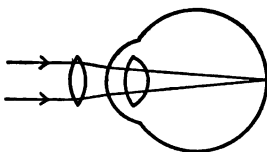


FIG. 382

Farsighted eye and correction by use of convex glasses

361. Astigmatism. *Astigmatism* is a defect of the eye due to a distortion of the image on the retina. This distortion may be caused either by irregularities in the shape of the eyeball or a lack of symmetry in the crystalline lens. The defect of astigmatism may be detected by looking at a series of radiating lines, Fig. 383. If the eye be astigmatic the radiating lines will not all be seen with equal distinctness. Astigmatism may be corrected by the use of specially ground lenses which compensate for the defects of curvature in the eye.

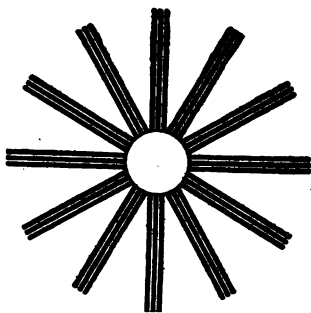


FIG. 383

Test for astigmatism

362. The Visual Angle and Apparent Size of Objects. The *visual angle* is the angle formed by rays passing from the extremities of an object and intersecting at the eye, Fig. 384. The size of this angle depends (a) upon the size of the object and (b) upon its distance from the eye; the greater the distance the less the visual angle. Now the apparent size of an object depends upon the size of the visual angle, because this angle determines the size of the image formed upon the retina.

Therefore the smaller the visual angle the smaller will be the image on the retina, and consequently the smaller the apparent size of the object. If one look along a railroad track the rails appear to approach each other and the ties to grow shorter, due to the fact that the visual angle diminishes

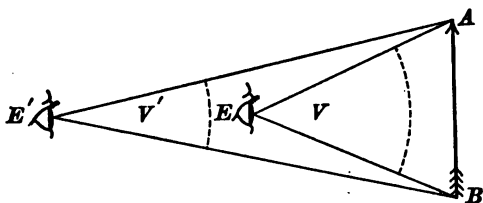


FIG. 384.—Visual angle

as the distance increases. We are enabled to judge of the real height and size of objects which are at a considerable distance only by calling on our past experiences and judgments.

363. Distance of Distinct Vision. Distinctness of vision depends upon the size of the image formed on the retina; therefore it may be assumed that the nearer an object is brought to the eye the more distinct it will become. Common experience teaches us that this is true only within certain limits, which may be determined by experiment. If the page of a book be held off at arm's length the printed matter will not be distinct enough for most people to read with ease. Upon bringing the book gradually nearer, however, the type will become more distinct as the page approaches, up to a certain point, from which position it will gradually grow dim again.

The distance at which the type appears most distinct is called the *distance of distinct vision*; it is for most normal eyes about 10 inches or 25 centimeters. The limit of distinct vision is determined by the power of the crystalline lens to change its shape and thus focus the image upon the retina.

364. The Camera. The photographer's camera is an instrument used for the printing of pictures by the action of the light upon chemically prepared films. It consists of a light-proof box having an adjustable lens, Fig. 385. The essential features of the camera consist of the adjustment of the objective lens until a sharp image of the object to be photographed is formed upon the film. The image formed in the camera is real and inverted.

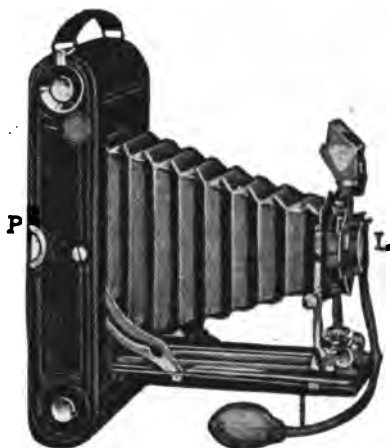


FIG. 385.—Camera

365. Duration of Visual Impressions. The duration of a visual impression depends upon the sensitiveness of the retina and the intensity of the light, the average time being estimated as about *half a second*. Distinct impressions, therefore, cannot be made upon the retina unless they succeed each other at intervals greater than that of the duration of the visual impressions for the given individual. It is this persistence of impressions on the retina that makes a swiftly moving object appear as a continuous line. Thus the spokes of a rapidly revolving wheel appear to blend into one another, and in a similar manner a burning stick, whirled rapidly around at night gives the impression of a continuous circle of flame. For this reason, also, shooting stars appear to have luminous tails behind them, and an electric arc lamp, fed with an alternating current of frequency greater than 25 cycles per second, appears to give a continuous light. If the arc be photographed, however, on a rapidly moving plate,

it will be found that the light is extinguished, that is, diminishes to zero intensity, with every reversal of the current, thus showing that it is really discontinuous.

366. Moving Pictures. The successful presentation of moving pictures depends in large measure upon the persistence of vision of which we have just been speaking. In the preparation of moving pictures a camera is employed which takes a series of snapshots upon a film which moves forward by jerks, usually at the rate of sixteen pictures per second. While the film is being jerked forward a shutter, operated mechanically, momentarily covers the lens. The pictures are taken between jerks, at which time the shutter is removed, exposing the lens. The usual length of film per reel is 1000 feet; this contains 16,000 pictures. From the negative reel of film positive films are printed for use in the "movie" projection lantern.

As we have stated, the pictures projected upon the screen move forward by jerks, sixteen pictures appearing per second. While the film is in motion the light is cut off by the shutter in the machine, and consequently at that instant the screen is perfectly dark. The eye, however, because of the duration of vision, detects no period of darkness, but continues to see the picture which was visible the instant before. Before the vision of this picture dies out another flashes into view, and so on. It thus appears that the so-called moving pictures do not move at all so far as retinal vision is concerned. To be sure the pictures on the reel move forward at the rate of sixteen per second, but the series of pictures which the eye perceives are for the instant stationary, the gap between any one and the next succeeding picture being filled by the power of the retina to retain visual impressions.

The moving picture is not only a valuable adjunct in the realm of entertainment and amusement, but it is undoubtedly destined to become an important factor in the educational field. (a) In the first place, certain subjects, as civics, history, literature, physics, etc., may be presented in a most striking

manner through the medium of moving pictures. (b) Second, operations and processes which can ordinarily be observed by only a single person at a time, such as the circulation of the blood as seen in a high power microscope, may be presented with every detail of reality to an entire audience. (c) Processes, such as the growth of a plant, which take a long time for completion, may be shown within the space of a few seconds. In order to present such a picture of the growth of a seedling it is necessary to take a series of pictures from time to time as the process goes forward. The positive film developed from the series of pictures on the negative is then run through the machine rapidly, thus presenting to the eye in a very short time a series of processes which may have required days or weeks to secure as negatives. (d) And finally, processes which take place very rapidly may be slowed up in presentation so that each detail may be studied. For example, a bullet fired from a gun may be photographed in its passage through a soap bubble, Fig. 386. It is interesting to note that the soap bubble breaks on the side at which the bullet leaves and not on the side of the bubble at which it enters.

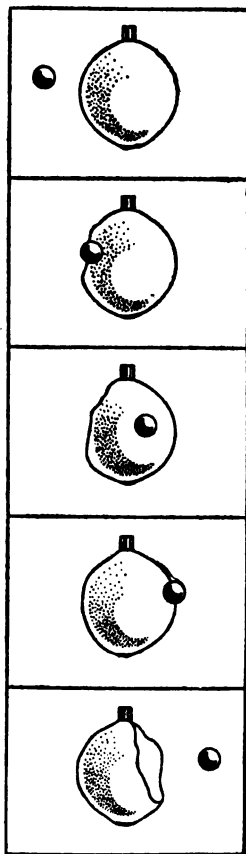


FIG. 386
Moving picture showing
the passage of a bullet
through a soap bubble

367. Visual Judgments. The eye has been likened to a camera, and so far as the physical principles involved are concerned, the likeness is very striking.

The impressions received from the eye, however, are quite different from those given by a photograph, and for two reasons. In the first place a

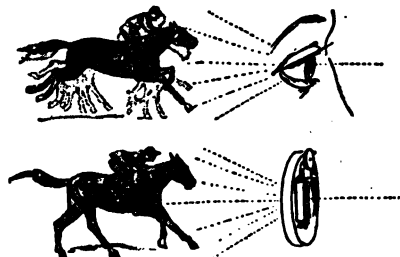


FIG. 387.—Images as formed by the eye and the camera lens

photograph gives a picture of an object in a given position, while the brain receives from the eye a composite impression. The difference between these two effects is very well shown in the comparison of a snapshot photograph of a horse in

the act of running, with that of a simultaneous impression received from the eye, Fig. 387. And in the second place, our

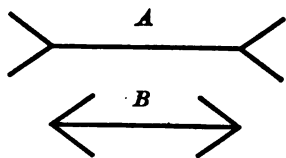


FIG. 388.—Horizontal lines A and B are of the same length

judgments of the position, size, and form of objects depend not only upon the images formed by the eye, but also upon our past experience. Sometimes our judgment is at fault, however, giving rise to optical illusions of various sorts. Thus in Fig. 388 the two horizontal lines are of exactly the same length. Line A appears to be longer than B because of the effect of the oblique lines at the ends.

COLOR AND DISPERSION

368. Introductory. Light, we have learned, is a vibration which is capable of affecting the organs of sight. *Color*, on the other hand, is a sensation; it depends upon the wave length and frequency of the light which falls upon the retina. The color of red is due to light of relatively long wave length, violet is due to light of short wave length. We cannot properly speak of red light or violet light, since the waves which give

rise to these sensations (colors) are in themselves colorless. When light waves making 395 trillion vibrations per second fall upon the retina they give rise to a sensation which we have been taught to call red; and likewise, light waves making 760 trillion vibrations per second give rise to a sensation which we call violet. In a similar manner we can account for all the intermediate color sensations.

It must be noted here that light is the cause of color and that the two important conditions for the production of color are (a) the presence of light of a given wave length, and (b) a sensorium (nerves and nerve centers) to receive the impression. If there were, therefore, no eye to receive the impressions of the light waves there would be no color.

Color, like the pitch of a musical tone in sound, depends upon the frequency, that is, upon the number of vibrations per second. The human ear is capable of perceiving musical notes covering a frequency range of about ten octaves, that is, from 30 vibrations per second to about 30,000. The human eye, on the other hand, is capable of perceiving colors over a frequency range of only one octave, that is, from 395 trillion vibrations per second to about 760 trillion.

369. The Solar Spectrum. If a beam of white light from the sun or an electric arc be allowed to pass through a prism

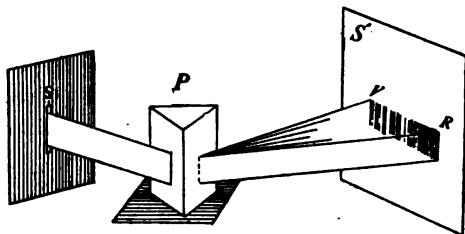


FIG. 389.—Dispersion of white light by means of a prism

and fall upon a white screen, it may be observed that the band of white light is broken up into seven colors of the solar spectrum, as shown in Fig. 389.

A *spectrum* is the color or series of colors of which the light from a given source is composed. This breaking up of white light into prismatic colors is called *dispersion*. It will be observed from Fig. 389 that the red is refracted least and the violet most. The colors of the *solar spectrum* are, in order of their refraction: *red, orange, yellow, green, blue, indigo, violet*.

TABLE XXIII

WAVE LENGTH AND FREQUENCY OF THE COLORS OF THE SOLAR SPECTRUM

<i>Color</i>		<i>Wave Length in mm</i>	<i>No. Vibrations per Second</i>
Red.....	A.....	.000760.....	395,000,000,000,000
Orange.....	C.....	.000656.....	458,000,000,000,000
Yellow.....	D.....	.000589.....	510,000,000,000,000
Green.....	E.....	.000527.....	570,000,000,000,000
Blue.....	F.....	.000486.....	618,000,000,000,000
Indigo.....	G.....	.000431.....	697,000,000,000,000
Violet.....	H.....	.000397.....	760,000,000,000,000

370. The Rainbow. One of the most familiar and striking examples of dispersion is that seen in the rainbow. In order to see a rainbow three conditions are necessary: (a) There must be drops of water in a cloud or mist; (b) the sun must be shining on the cloud; and (c) the eye of the observer must be in such a position as to receive the refracted light from the raindrop; that is, the observer must stand with his back to the sun.

A rainbow may be formed experimentally as follows: Allow a strong beam of light from the sun or an electric lantern to pass through a circular opening in a screen and fall upon a spherical flask full of water, Fig. 390. The flask represents a large drop of water in which the light is both refracted and reflected; that is, it is refracted on entering the flask and

reflected from the rear surface, being thus thrown back upon the screen, forming a circular band of color, red on the outside and violet on the inside. This colored band upon the screen, formed by the dispersion of white light by the spherical flask, is similar to that of the rainbow.

There are two rainbows, the primary and the secondary. The *primary bow*, which is the one usually observed, is much

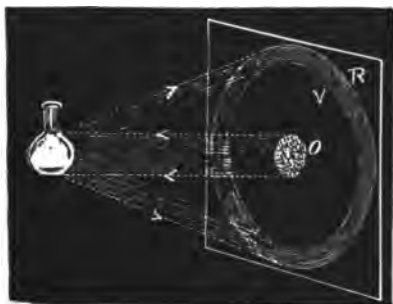


FIG. 390.—Laboratory method of forming a rainbow

the brighter of the two and lies inside the secondary. In the *primary bow* the red is on the outside and the violet on the inside. The *secondary bow* is the fainter of the two, and in fact is not usually seen except under very favorable conditions. Its colors are reversed as compared with those of the primary, the violet being on the outside and the red on the inside.

In Fig. 391 we have given a more or less ideal sketch illustrating the relation of the primary to the secondary bow with reference to the number of reflections and refractions in each. The margin of each bow is selected for illustration. In order to see both bows, the eye *E* must be in such a position with respect to the sun *S* that the light refracted and dispersed by the drops will make a definite angle with the line of direction of the sun's rays. This angle depends upon the index of refraction of the drop and the color seen by the eye. This angle varies from color to color since the index of refraction

of the different colors of the spectrum vary. The angle REC for red of the primary bow is 42° , that of violet, VEC , 40° ; for the secondary bow the angles are, for violet 54° , for red 51° . The reason that the rainbow is circular, then, is that the color from only those drops which make a definite angle with EC

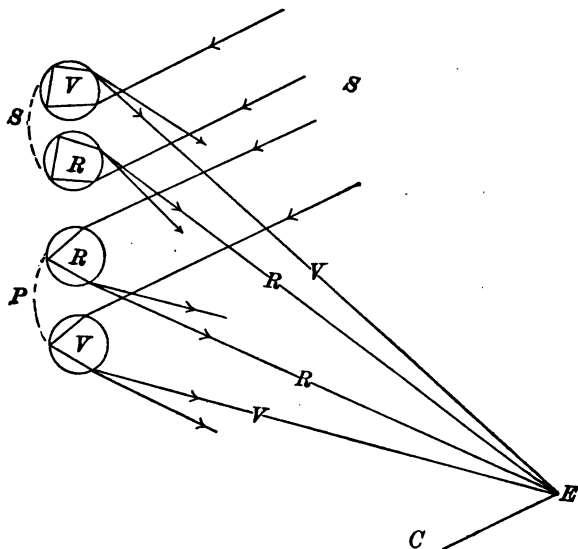


FIG. 391.—Diagram illustrating the formation of primary and secondary rainbows

are seen by the eye. In other words, the eye is at the vertex of a cone, a portion of the base of which is a circle forming the rainbow.

It will be observed that light forming a primary bow suffers two refractions and one internal reflection; the secondary bow, two refractions and two reflections. Now since some light is lost at each reflecting surface, it is easy to understand why the primary bow is the brighter of the two.

371. Kinds of Spectra. There are three kinds of spectra, as shown in Figs. 392, 393, 394.

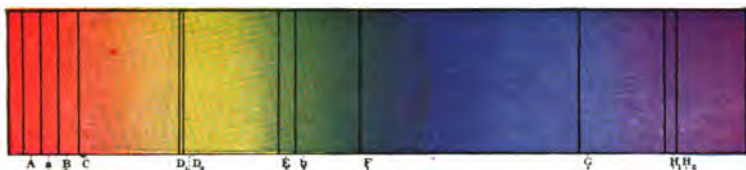


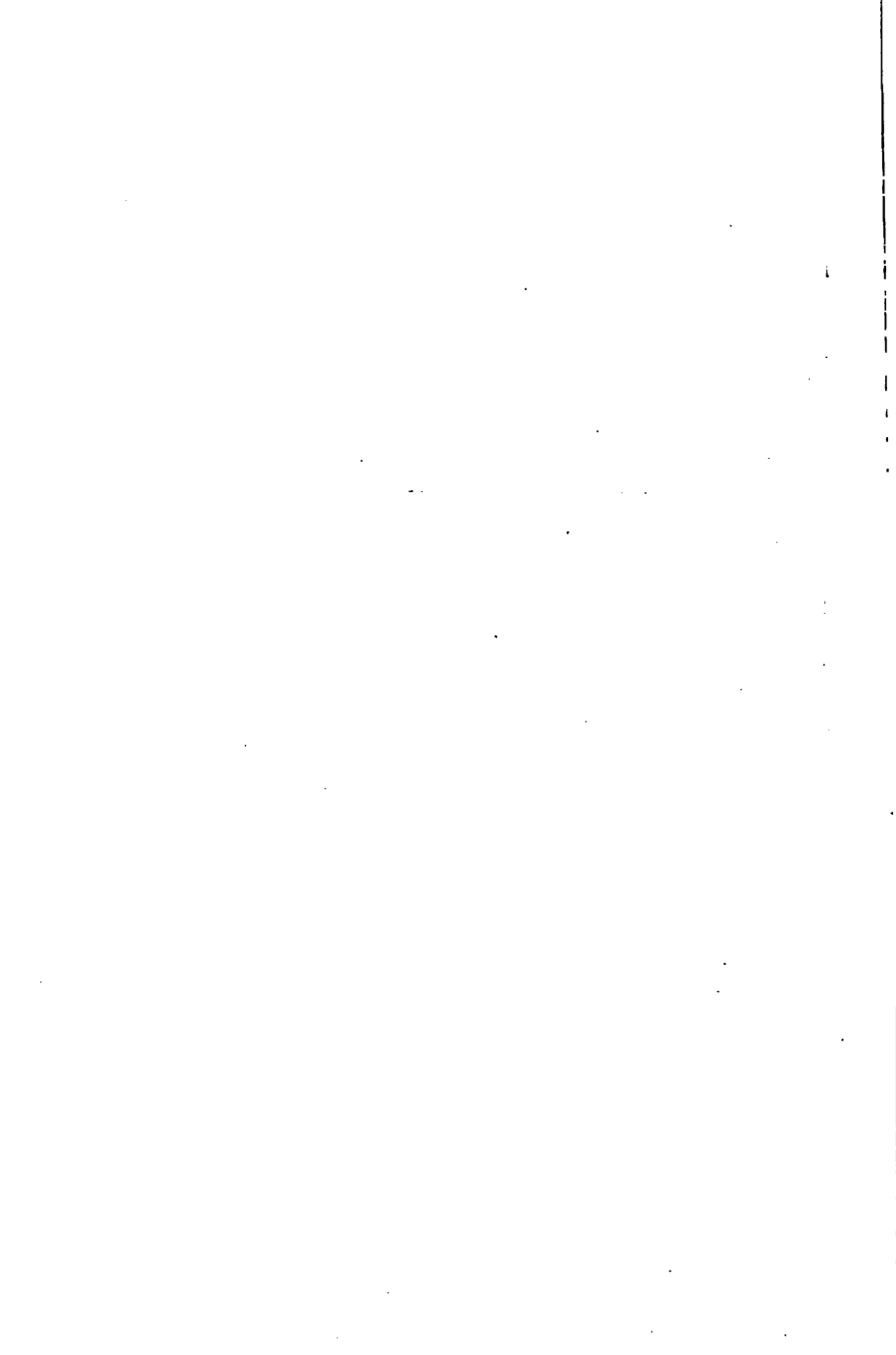
Fig. 392. Solar Spectrum. Crossing this spectrum there are many dark lines which are called Fraunhofer lines. Such a spectrum is very appropriately called a Dark Line Spectrum. These lines, however, are not visible under ordinary conditions without the aid of a spectroscope.



Fig. 393. Continuous Spectrum. The colors of a continuous spectrum blend one into the other without any dark lines occurring, as in the case of the spectrum of Fig. 392. A continuous spectrum is due to incandescent solids, such as the carbons of the electric arc, or the glowing filament of an incandescent lamp.



Fig. 394. Bright Line Spectrum. A bright line spectrum is formed by the light from an incandescent gas. Each metal, for example, when in a volatile condition and heated to incandescence gives rise to its own characteristic bright line spectrum, the above being that of sodium.



A *dark-line spectrum*, Fig. 392, is one in which dark lines appear at intervals across the color band of which the spectrum is composed. Such a spectrum is formed when the light from an incandescent solid passes through that of an incandescent gas. The solar spectrum is a dark-line spectrum. It is true that it appears to the naked eye to be continuous. If, however, the solar spectrum be examined by means of a spectroscope, it will be found that many dark lines appear in it, as shown in Fig. 391. These are called *Fraunhofer lines*, after Joseph Fraunhofer, a German scientist, who was one of the first to count and describe them. The fact that the sun's spectrum is a dark-line spectrum tells us that its light comes from an incandescent solid, liquid, or gas under high pressure surrounded by an incandescent gas under relatively low pressure.

A *continuous spectrum*, Fig. 393, is one in which the colors blend gradually from one into the other without any break. The spectrum from an arc lamp is continuous, the colors grading continuously from red to violet. An incandescent solid gives a continuous spectrum. The spectrum from a gas flame, or a candle flame, or the flame of a kerosene lamp is in all cases continuous, the luminous properties of such flames being due to the red-hot solid particles which they contain. Likewise a platinum wire or any other metal heated to incandescence gives a continuous spectrum.

A *bright-line spectrum*, Fig. 394, is one consisting of one or more bright lines. A bright-line spectrum is formed from an incandescent gas. Thus if a piece of sodium be placed in the flame of a Bunsen burner and the yellow light examined by means of a spectroscope, a bright yellow band will appear. This is a bright-line spectrum. So long as a substance remains in the state of an incandescent solid it gives a continuous spectrum; the moment, however, that it becomes gasified and incandescent, it gives a bright-line spectrum.

372. Spectrum Analysis. If any substance in the condition of an incandescent gas be examined by means of a spectro-

scope, Fig. 395, it is possible to determine from the nature of its spectra many facts regarding the character of the substance. For example, suppose that we wish to determine if there is any sodium in a given inorganic substance. Dip a platinum wire into the substance and then place it in the colorless part of a Bunsen flame; the salt will be volatilized, and if any sodium



FIG. 395.—Spectroscope

be present a distinct yellow color will be imparted to the flame. If this be examined by means of a *spectroscope* the presence of even the most minute trace of sodium will reveal itself by the appearance of a yellow band. Thus it is possible to determine the presence of $1/14,000,000$ gram of sodium.

Also, when the spectrum of the sun and the stars are examined and we find present the lines that are characteristic of sodium, iron, magnesium, and other metals we take for granted that these metals are present in the heavenly bodies from which the light comes.

373. The Invisible Spectrum. The visible spectrum is that which is included between red and violet, about one octave of color; that is, from red making 395 trillion to violet which makes 760 trillion vibrations per second. The visible spectrum, however, is not the limit of the dispersion of ether waves which may be secured by a prism. Beyond the red is a series of longer waves which manifest themselves to our senses in the

form of heat. Below the violet there are very short waves which are capable of great chemical activity. The invisible rays beyond the red are called the *infra-red*; those beyond the violet are called the *ultra-violet*.

374. Analysis and Synthesis of White Light. The white light of the sun may be considered as made up of many colors, the most striking of which are the seven so-called spectral colors which appear when white light is dispersed by a prism. The question naturally arises: Is it possible to combine these seven colors so that they may give us again white light? Sir Isaac Newton asked himself this very question and was one of the first to answer it by means of an experiment. He first passed a beam of white light through a prism, causing it to become dispersed; he then passed the dispersed beam through a second prism, inverted with respect to the first, Fig. 396, and found that the colors of the spectrum were combined by the second prism into a band of pure white light.

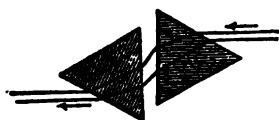


FIG. 396

Analysis and synthesis of white light

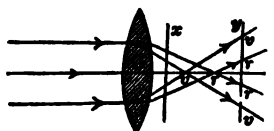


FIG. 397

Chromatic aberration

The breaking up of white light into its spectral colors is called **analysis of white light**; the combining of these colors is called **synthesis**.

375. Chromatic Aberration. When white light passes through a lens two things occur: (a) it is refracted and (b) it is to a certain extent dispersed; that is, it is broken up into prismatic colors. This dispersion of white light which occurs in a lens is called *chromatic aberration* and is illustrated in Fig. 397. The violet rays, being the most refrangible, come to a focus nearer the lens than do those of the red. If, therefore, a white card be placed in the light at *x* there may be

observed around the outer edge a fringe of red; if the card be placed at y there will be seen around the outer edge a fringe of violet. This fringe of color constitutes a very serious defect in the image, especially where it is desired to produce a clear image, as in the case of the microscope. The *remedy for chromatic aberration* lies in the use of two lenses, one concave

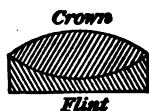


FIG. 398
Achromatic lens

and the other convex, of different kinds of glass ground so as to fit closely one upon the other. In Fig. 398 there is shown an *achromatic lens* consisting of a bi-convex lens of crown glass and a plano-concave lens of flint class. The light passing through such a lens is brought to a focus without being dispersed. Lenses of this type are used in the objective of the compound microscope.

376. Mixing Colors.

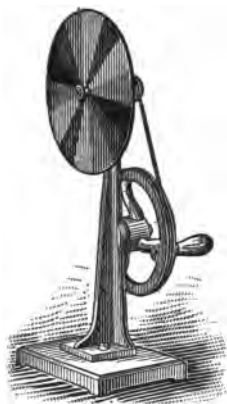


FIG. 399
Newton's color disc

Since color is a sensation, it follows that the mixing of colors is nothing more than the mixing of sensations. If a color disc, sometimes known as Newton's disc, Fig. 399, be rapidly rotated, the eye will receive a series of impressions, the resultant sensation of which will be caused by the mixing of the several sensations due to the different colors on the disc. Thus if the disc be rotated the eye will no longer see yellow, blue, green, etc., but will see in their stead gray or white, or whatever the resultant color may be.

377. Complementary Colors. Any two colors which when mixed produce the sensation of white are called *complementary colors*. A complementary color disc is shown in Fig. 400. Those colors which are opposite each other on the disc will, on being mixed, produce white. Thus yellow and dark blue are complementary, as may be shown by the following very simple experiment.

Place a yellow and a blue strip of paper a few inches apart on the table and then view them by means of a piece of glass as shown in Fig. 401. The sensation produced, that is, the resultant color, will be neither blue nor yellow, but white. The light from the blue reaches the eye by passing through the

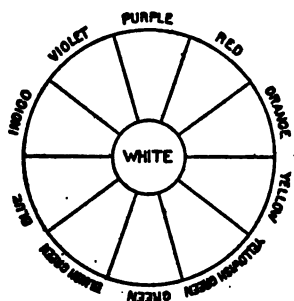


FIG. 400
Complementary color disc

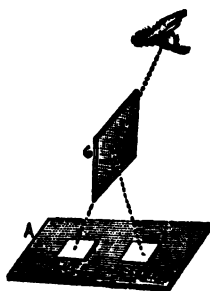


FIG. 401
A method of mixing colors

glass; that from the yellow by reflection from the glass. Both trains of light waves thus unite and give rise to the common sensation of white.

Those colors which produce the sharpest contrast are in general complementary to each other. For example, red and green are complementary colors. When these colors are brought near together the red appears redder and the green greener. Thus the red rose appears redder when seen against the background of green leaves than it otherwise would. Blue also appears bluer when placed adjacent to a yellow field.

378. Mixing Pigments. We have just learned that when the colors (sensations) blue and yellow are mixed they produce white. Now, however, if yellow and blue pigments be mixed, in the sense in which the painter mixes colors, the resulting color will not be white, but green. This can easily be shown by mixing yellow and blue pigments from a set of water colors.

The effect of mixing pigments can also be shown by making on the blackboard with a blue crayon a broad band of blue; then over the blue make a corresponding band of yellow. The mixture of blue and yellow crayon will give a color of greenish tinge.

Mixing pigments then produces an entirely different effect from the mixing of corresponding colors. Yellow and blue colors, to repeat, produce white; yellow and blue pigments produce green. The reason that the mixing of blue and yellow pigments produces green is because the blue pigment absorbs all the colors of white light except blue and green, and the yellow pigment absorbs all but the red, yellow, and green. Now when the two are mixed there results a pigment that absorbs every color but green, which is reflected. In a similar manner we may explain the resulting color due to mixing any number of pigments. If, for example, we should take a combination of pigments of such a nature that the mixture would absorb all the colors of white light, the resulting mixture would be black.

379. The Color of Bodies. The color of any body is due to the character of the light which it reflects, or transmits. If it reflects light having a wave length of about 0.0007 millimeter it gives rise to the color of red, and so on throughout the color scale. We often speak of an object as being painted a given color, as, for example, red. What is really done is to put upon the object a pigment which has the property of absorbing the light of all colors excepting red, or green, or whatever the color may be. Also, if a piece of glass be held up before the sunlight, and the light which passes through it falls upon the eye and we receive the impression of red, we say that the glass is red. It is red simply because it has the property of absorbing all the colors except those which give rise to the sensation of red, which wave length it transmits. That is, the glass absorbs all other waves and transmits only those that produce red.

This all means that the color of any object is not something that resides within the object, but is a sensation having its seat within the brain of the observer. The red of the rose, for example, is not in the rose, but in the sensorium of the observer. The rose simply has the property of reflecting those waves which give rise to the sensation of red.

380. Colors Due to Thin Films. If a soap bubble be observed in the sunlight, brilliant colors will be seen shifting rapidly across the surface of the bubble. These colors, due to thin films, are caused by what is known as *interference*. This can best be explained in an elementary way by means of Fig. 402. Since the light is a wave motion, it follows that two waves may interfere in almost exactly the same way that two sound waves interfere. It is possible, therefore, that two light waves may be superimposed one upon the other in such a way that one may exactly neutralize the other. If the light be white light, that is, light consisting of the seven prismatic colors, and one color be cut out, due to interference, then the remaining colors of the spectrum will appear. Consider a band of light, *ab*, as falling upon a thin film, *AB*. Part of this light is reflected and part passes through to the second face of the film and is then reflected. Now if it happens that a part of the wave train *a* which emerges at *c* should unite with the reflected part of *b* in *opposite phase*, then interference will occur.

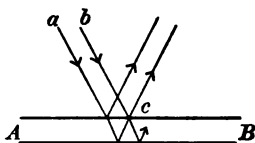


FIG. 402.—Interference of light

This, in general, is the explanation of the brilliant bands of color which occur in the case of a soap film. The shifting of these bands is due to the fact that the film is constantly changing its thickness. Other illustrations of interference are seen in the bright colored bands which appear when a film of oil spreads out over the surface of water; also the bright bands which appear due to cracks in ice, or in other crystalline substances, illustrate interference effects.

REVIEW EXERCISES

1. Name three theories of the transmission of light, and give the names of the physicists who advanced them.
2. Wherein do light waves differ from sound waves?
3. Define and illustrate (a) luminous body, (b) transparent body, (c) opaque body.
4. Define: (a) optics, (b) light.
5. Define and illustrate (a) ray, (b) beam, (c) pencil of light.
6. Define shadow, and illustrate by a sketch the different parts of a shadow.
7. Explain Roemer's method of determining the velocity of light. What is the velocity of light?
8. Compare (a) the velocity of light with that of sound; (b) the velocity of light in a vacuum with that in air; (c) velocity in air with that in glass.
9. It is said to take fifty-four and one-half years for light to travel from the North star to the earth. How far away is the North star?
10. The star Arcturus is 600,000,000,000 miles from the earth. Suppose that this star were suddenly extinguished, what time would elapse before astronomers could detect the fact?
11. Explain by means of a sketch why images formed through small apertures are inverted.
12. Explain what is meant by intensity of illumination, and state and illustrate the law of inverse squares.
13. Two planes are placed at a distance of 2 ft. and 3 ft. respectively from a given source of light. What must be the relative areas of the two planes in order that they intercept the same amount of light?
14. The page of a book is held 1 ft. from a given light. It is then removed to a distance of 5 ft. Compare the intensities of illumination of the pages in the two cases.
15. In the case of images formed through small apertures, how is the intensity of illumination affected by moving the source of light toward the aperture? How is the intensity of illumination affected by increasing the size of the aperture? What effect does this have on the distinctness of the image?
16. What is the unit of intensity called? The international unit of intensity of illumination is equivalent to (a) how many American electrical units of candlepower? (b) how many Hefner units?
17. Explain how a photometer may be used to measure candlepower?
18. State the law of reflection, and illustrate by means of a sketch (a) angle of incidence, (b) angle of reflection.
19. Define: (a) virtual image, (b) real image.

20. Given an object in front of a plane mirror. Find by drawing the position and character of the image formed. What is the relation of the image to the object with respect to its distance from mirror? Is the image real or virtual?

21. If a person walk toward a plane mirror with a velocity of 8 ft. per second, with what velocity does his image approach?

22. Explain the formation of multiple images.

23. Define and illustrate by drawing with reference to a spherical mirror the following terms: (a) center of curvature; (b) vertex; (c) principal axis; (d) principal focus; (e) secondary axis.

24. Where must an object be placed with reference to the focus of a spherical mirror in order that the image be real and (a) larger than the object? (b) smaller than the object?

25. In what two positions with reference to spherical mirrors may an object be placed so that the image is virtual? Make drawing to illustrate each.

26. The radius of curvature of a concave mirror is 30 cm. An object is placed on the principal axis 50 cm from the vertex of the mirror. Is the image (a) real or virtual? (b) erect or inverted? (c) larger or smaller than the object?

27. (a) Define and explain spherical aberration in spherical mirrors. (b) Explain the formation of the "caustic."

28. Define and explain refraction. Explain how light is refracted with reference to the normal when it passes (a) from a rare to a dense medium; (b) from a dense to a rare medium.

29. A man standing on the bank of a stream wishes to spear a fish which lies in the water below him. Should he strike above or below the apparent position of the fish?

30. Trace a ray of light (a) through a plate glass having parallel surfaces; (b) through a prism.

31. Define index of refraction. What does it mean when we say that the index of refraction of water is $\frac{4}{3}$? What is the velocity of light in water?

32. Considering the index of refraction of crown glass to be 1.5, what is the velocity of light in crown glass?

33. What is a convex lens? What is its effect on parallel rays of light? Name and illustrate by drawing the three classes of convex lenses.

34. What is a concave lens? What is its effect on parallel rays of light? Name and illustrate the three classes of concave lenses.

35. Where must an object be placed with reference to the focus of a convex lens in order that the image be real and (a) smaller than the object? (b) larger than the object?

36. In what position must an object be placed with reference to a convex lens in order to produce a magnified virtual image? Illustrate by a sketch.

37. Make a sketch to illustrate the position and character of the image formed by a concave lens.

38. Define and illustrate spherical aberration in the case of a lens, and state how it may be remedied.

39. Make a sketch to illustrate the principle of the simple microscope.

40. Make a sketch to illustrate the principle of the compound microscope.

41. Explain wherein a telescope differs from a compound microscope.

42. Make a sketch to illustrate a cross section of the human eye. Name the different parts and explain the function of each.

43. Make a sketch to illustrate a nearsighted eye, and explain how this defect may be remedied.

44. Make a sketch to illustrate a farsighted eye, and explain how this defect may be remedied.

45. What is astigmatism, and how may its presence be determined?

46. Make sketch to illustrate visual angle. What is the relation of the apparent size of an object to the visual angle?

47. What is the distance of distinct vision for the ordinary eye? What is the distance in your case? Is it the same for both eyes?

48. (a) What is meant by "persistence of visual impression"? What is the average duration of distinct vision? What modern application has there been of this power of the eye to retain visual impressions?

49. (a) Define color, and name the colors of the solar spectrum. (b) Compare the vibration frequency of light producing the color red with that producing violet.

50. The speed of light is 300,000 km per second, and the wave length of red light is 0.0007 mm. How many waves of light of this color will strike the eye in one second?

51. If the waves producing the sensation of red were all absorbed from sunlight, what color would objects that were formerly red appear to have?

52. (a) Explain by means of a sketch the formation of primary and secondary rainbows. (b) Name the colors in each, in order.

53. Suppose that a person were in a balloon above the clouds, what shape of rainbow might it be possible to see?

54. (a) What is a continuous spectrum? (b) dark line spectrum? (c) bright line spectrum? (d) Under what conditions is each formed?

55. What are complementary colors? Give some examples. How do complementary colors affect each other when placed side by side?

CHAPTER IX

MAGNETISM AND ELECTROSTATICS

MAGNETISM

381. Introductory. One of the oldest and at the same time one of the most interesting pieces of electrical apparatus is the magnet. The small horseshoe magnet with its mysterious power of attracting objects made of iron and steel, Fig. 403, is familiar to every school boy; and the study of the applications

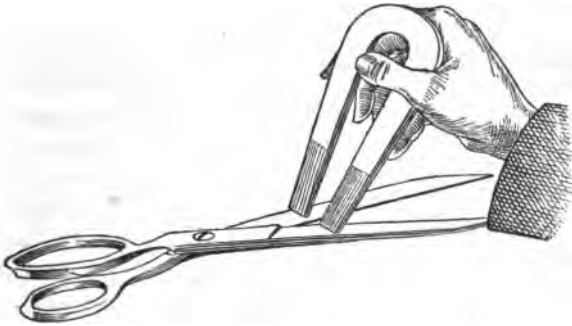


FIG. 403.—Horseshoe magnet attracting steel

of magnetic attraction and repulsion, entering as these properties do into nearly every household and commercial electrical device, is of great interest and importance to the physicist and electrical engineer. The magnet was known and its properties applied by the Chinese at a very early date in the history of civilization; indeed, the magnetic compass was invented in China and was introduced into Europe from that country as early as 1300 A. D.

In many parts of the earth there is found a kind of iron ore which possesses the properties of a magnet; that is, it attracts iron, and when suspended so as to swing freely about a vertical

axis it points in a north-south direction. This ore is called *magnetite* and its chemical composition is represented by the



FIG. 404
Natural magnet attracting iron

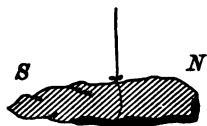


FIG. 405
Lodestone pointing in a
north-south direction

formula Fe_3O_4 , that is to say, a molecule of magnetite contains 3 atoms of iron and 4 atoms of oxygen. A piece of this ore is called a *natural magnet* or *lodestone*. A natural magnet to which

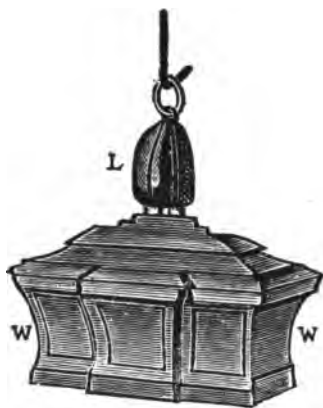


FIG. 406
Galileo's lodestone (L), one of
the most interesting historical
magnetic relics in the world

iron filings are clinging is shown in Fig. 404. The term lodestone (leading stone) probably came from the fact that elongated pieces of magnetite were employed in early times by navigators as a sort of crude mariner's compass, Fig. 405. In Fig. 406 there is shown Galileo's lodestone, *L*, one of the most interesting exhibits in the world, especially to electricians. This stone, after 300 years, holds as firmly as ever the suspended

iron weight, *W*, suspended at the bottom of the lodestone is made in the form of a sepulcher.

The electric door bell, the telephone, the telegraph, and the electric generator and motor are only a few of the modern appliances in which magnets are used in one form or another.

382. Characteristic Properties of the Magnet. The characteristic properties of the magnet may be demonstrated experimentally as follows: (a) *Magnetic attraction.* Bring one end of a bar magnet near some pieces of iron, such as small nails, tacks, or iron filings. The magnet attracts the iron. The filings leap to the poles of the magnet and cling tenaciously. (b) *Magnetic polarity.* Roll the magnet in iron filings; tufts of the filings cling to the ends of the bar, while few or none are attracted to the middle part, Fig. 407. The ends to which



FIG. 407.—Magnet, showing tufts of iron filings clinging to the poles

the filings cling are the magnetic poles. (c) *Magnetic orientation.* Now suspend a light bar magnet (a magnetized knitting needle will do) so as to move freely about an axis, Fig. 408. The magnetic needle takes a north-south position, the

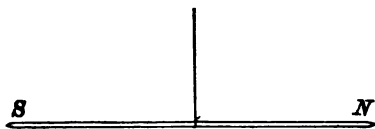


FIG. 408.—Magnetic needle, showing north- and south-seeking poles

end pointing toward the north being called the *north-seeking pole*; the end pointing to the south, the *south-seeking pole*. The north-seeking pole is usually marked *N* or $+$; the south-seeking-pole, *S* or $-$.

A straight line joining the *N* and *S* poles of a magnet is called the *magnetic axis*.

383. How to Magnetize a Body. If a piece of steel, such as a bit of clock spring, a needle, or the blade of a pocket knife, be drawn several times in one direction across the end of a magnet, it will itself become a magnet. Consider, for example, the case of the knife. If the blade be drawn across the N-pole of the magnet from heel to point, the heel of the blade will be an N-pole and the point an S-pole, Fig. 409.

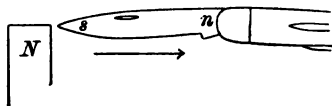


FIG. 409.—Magnetizing a knife blade

If the blade be drawn in a similar manner across the S-pole of the magnet, the polarity of the blade will be reversed. The greater the number of times the steel is drawn across the mag-

net, the greater will be the pole strength, up to a certain point at which the steel is said to become magnetically saturated.

384. Magnetic Substances. If the pole of a magnet be brought successively in contact with pieces of iron, copper, brass, wood, and paper it will be found that the iron is strongly attracted, while the copper, brass, wood, and paper are not noticeably affected. The iron is magnetic; the others are non-magnetic. A *magnetic substance* is one that is attracted or repelled by a magnet. Iron is highly magnetic; cobalt and nickel are also magnetic, but to a less degree than iron. Some magnetic substances, antimony (Sb) and bismuth (Bi) for instance, are slightly repelled by a magnet and are said to be *diamagnetic*.

385. Kinds of Magnets. Magnets may be classified in various ways, as for example: (a) natural and artificial magnets; (b) permanent and temporary magnets; and with reference to their form, (c) bar and horseshoe magnets. All manufactured magnets are artificial magnets. Permanent magnets are made of highly tempered steel and retain their magnetic properties for a long time; magnets made of soft iron soon lose their magnetic properties, and for this reason are called temporary magnets. Whether the magnet be of

the bar or horseshoe form is determined by its use. When we desire to use a single pole, the bar magnet is the more convenient; when, on the other hand, the maximum lifting effect is desired, the horseshoe type is employed. Some-



FIG. 410

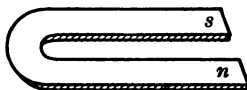


FIG. 411

Bar and horseshoe magnets

times a short piece of soft iron, called an armature or keeper, is placed across the ends of the magnet when the latter is not in use. The reason for using a keeper is to prevent the magnet from losing its strength, as will be explained later.



FIG. 412.—Eye magnet, used by physicians for removing particles of iron or steel from the eye

In Fig. 412 there is shown an eye magnet, such as is frequently employed by physicians to remove particles of iron or steel from the eye.

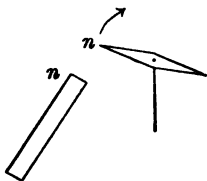


FIG. 413

Like poles repel; unlike poles attract

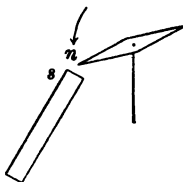


FIG. 414

386. Law of Attraction and Repulsion. (a) Present to the north-seeking pole of the magnetic needle the N-pole of a magnet, Fig. 413; the like poles repel. Now present to the

north-seeking pole of the needle the S-pole of the magnet, Fig. 414; the unlike poles attract.

(b) The force of attraction or repulsion between two magnetic poles in a given medium depends upon the strength of the poles, and upon the distance which they are apart. First, the force of attraction or repulsion is *directly* proportional to the product of the respective pole strengths. For example, at unit distance (1 cm) apart in air, the force acting between poles of 2 and 3 units strength is $2 \times 3 = 6$ dynes; and again, the force between poles of 4 and 5 units respectively is $4 \times 5 = 20$ dynes. Second, for given poles, the force of attraction or repulsion varies *inversely* as the square of the distance between them. That is, if the force acting between poles at unit distance apart is 16 dynes, the force between the same poles when placed 2 centimeters is $16/2^2 = 4$ dynes.

(c) The force of attraction or repulsion depends upon the nature of the medium in which the poles are placed. For example, the magnetic attraction or repulsion of two given poles is slightly greater in a vacuum than in air.

The facts discussed in the foregoing paragraphs may be summarized in the following statement of the laws of magnetic attraction and repulsion:

I. *Like poles repel; unlike poles attract.*

II. *The force of attraction or repulsion between two poles varies directly as the product of the pole strengths, and inversely as the square of the distance between them.*

III. *The force of attraction or repulsion depends upon the nature of the medium in which the poles are immersed.*

387. Magnetic Field and Lines of Induction. The magnetic field is that portion of space surrounding a magnet which is affected by the magnet. The magnetic field may be mapped out by sprinkling fine iron filings upon a glass plate and placing the plate over a magnet. Tap the plate gently. The filings arrange themselves in curved lines, in response to the magnetic force acting upon them, Fig. 415. These lines were called

by Faraday lines of force, but since the tendency in modern practice is to use the term lines of induction, we shall throughout this text speak of the lines in the magnet field as *lines of induction*. *These lines of induction are conceived of as com-*

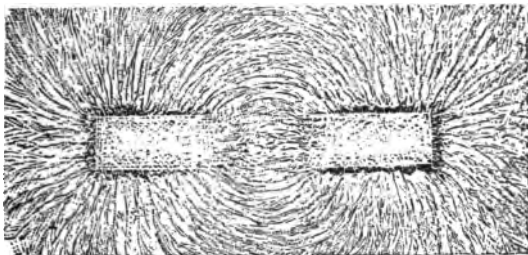


FIG. 415.—Magnetic field about a bar magnet

ing out of the N-pole and passing in closed curves around to the S-pole, and thence through the magnet back to the N-pole, as shown in Fig. 416.

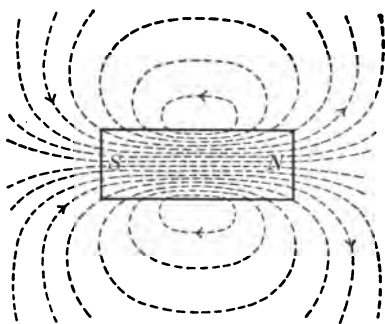


FIG. 416.—Lines of induction come out the N-pole and enter the S-pole

The position which a magnetic needle assumes is determined by the direction of the lines of induction of the field in which it is placed. When placed at a given point in a magnetic field, a magnetic needle always tends to take such a position

that the lines of induction of the field enter the S-pole of the needle and leave at the N-pole.

388. Magnetic Fields between Like and Unlike Poles.

(a) In Fig. 418 there is shown the condition of the lines of induction in a magnetic field between like poles. The lines

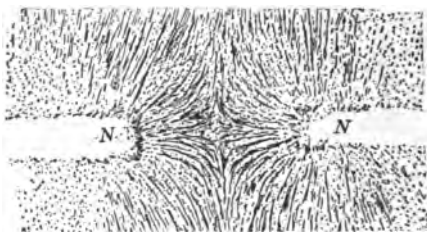


FIG. 417.—Magnetic field between like poles

of induction emanating from the respective N-poles are crowded together in the center of the field. This crowding together of the lines suggests an explanation of the fact that like poles repel.

(b) The field between unlike poles is shown in Fig. 418. Here the lines of induction are represented as leaving the N-pole

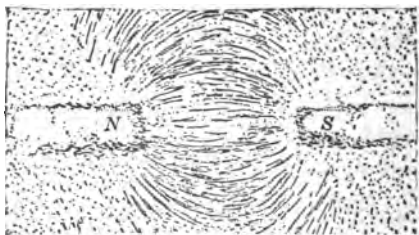


FIG. 418.—Magnetic field between unlike poles

and entering the S-pole by more or less curved lines. These curved lines of induction tend to contract, thus producing the phenomenon of attraction.

389. Magnetic Induction. We have seen that when a piece of iron is placed in contact with a magnet it too becomes magnetized. The iron may be magnetized, however, without actually coming in contact with the magnet. Place one end of a soft iron nail in iron filings, and then bring near to the other end of the nail the pole of a bar magnet. If now both nail and magnet be lifted it will be observed that the tufts of iron cling to the lower end of the nail, Fig. 419, thus showing that it is magnetized even though not in actual contact with the permanent magnet. When the magnet is removed, the nail at once loses its magnetism, the iron filing falling away. While the nail is influenced by the presence of the magnet, it is said to be magnetized by *induction*. If the pole of a magnet be brought near a piece of iron or other magnetic substance, there will be induced in the iron on the side next the magnet a pole of the opposite kind, and in the side farthest from the magnet, a pole of the same kind.

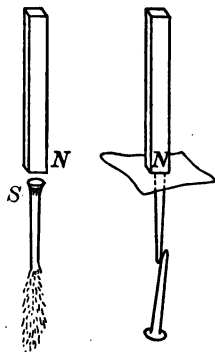


FIG. 419 FIG. 420
Magnetic induction
and magnetic
transparency

If now a piece of glass or a sheet of paper be slipped between the ends of the magnet and the nail, Fig. 420, it will be observed that the magnetic inductive effect upon the nail is practically undiminished. Many substances such as glass, paper, and wood seem to be transparent to magnetic induction. Such substances are said to be *magnetically transparent*.

390. Magnetic Shields. We have learned that glass is magnetically transparent. Iron on the other hand is not magnetically transparent in the sense in which glass is. This fact, together with the magnetic shielding effect of iron, is very well shown in Figs. 421, 422. In Fig. 421 there is shown the passage of the lines of induction through the sides of a glass

vessel placed in a strong magnetic field. Figure 422 illustrates the shielding effect of an iron ring, the lines of induction passing

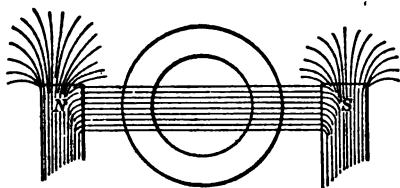


FIG. 421.—Magnetically transparent glass ring

around through the iron from one pole to the other. An object, a watch for example, placed at *A* within the ring will be effectually shielded from the magnetizing force of the field.

391. The Effect of Breaking a Magnet. Suppose that we magnetize a thin strip of steel (a piece of clock spring). It has a

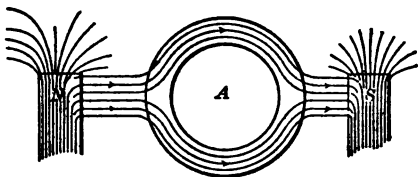


FIG. 422.—Magnetic shielding effect of a metal ring

pole at each end and a neutral point in the middle. Now if this magnet be broken at the middle it will be found that each piece is a magnet, Fig. 423. If each piece be again broken the smaller pieces will still be mag-

nets. Thus we may conceive the breaking process to go on until the molecule is reached. The conclusion from this and other experiments is that a magnet possesses its magnetic properties because of the fact that its molecules are magnets.

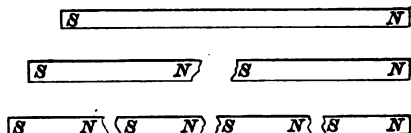


FIG. 423.—Effect of breaking a magnet

392. Molecular Condition of Unmagnetized and Magnetized Iron Bars. When a bar of iron is unmagnetized the molecules of which it is composed are supposed to lie with their poles in every conceivable direction, as shown in Fig. 424.

When the bar is magnetized the molecules are assumed to lie with their magnetic axes all in a definite direction, Fig. 425, that is, all the molecular n -poles pointing toward the N -pole of the bar and the molecular s -poles toward the S -pole.



FIG. 424



FIG. 425

Molecular condition of unmagnetized and magnetized bars

If a bar magnet be dropped or jarred violently, it is said to lose its magnetism. What really happens is that the molecules rearrange themselves again, taking up the positions as shown in Fig. 425. Strictly speaking, the bar has as much magnetism as before; what it has lost is its polarity.

393. Consequent Poles. Every magnet has two poles. A bar may be magnetized, however, so that it will have within itself a number of magnets, and hence a number of poles. The poles which occur in a magnet other than at the ends

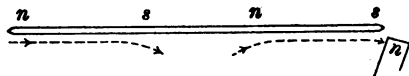


FIG. 426.—Consequent poles

are called *consequent poles*. If the poles of a permanent magnet be drawn along a piece of steel (knitting needle) skipping

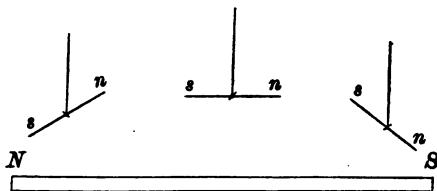


FIG. 427.—The earth a magnet

at several places, Fig. 426, the needle will contain two or more consequent poles. It is possible to magnetize a steel bar in such a way that both ends may be either N -poles or

S-poles. The bar will of course in this case contain consequent poles opposite in sign to those at the end.

394. The Earth a Magnet. Suspend above a long bar magnet NS , Fig. 427, a short magnetic needle ns . When the needle is at the neutral point, its position is horizontal; when it is carried from this point toward either pole, it dips more and more, until the pole is reached, when its position is vertical. Now if a magnetic dipping needle, Fig. 428, be

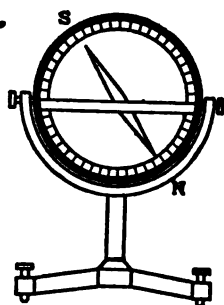


FIG. 428
Dipping needle

carried on the surface of the earth from the equator toward the poles, it will be observed to dip in a similar manner. This means that the earth behaves exactly as if it were a magnet, having one magnetic pole near the north geographic pole and the other near the south geographic pole. The earth's magnetic pole at the north corresponds to the S-pole of a bar magnet; the magnetic pole at the south corresponds to the N-pole of a bar magnet. Since unlike poles attract, we thus understand why the N-pole of a

needle points toward the north.

The magnetic poles of the earth do not coincide with the geographic poles, the magnetic pole of the north, for example, being more than 1000 miles from the geographic pole. The magnetic pole of the north was first located in 1831 by Sir James Ross at a point in Boothia Felix, Northern Canada. It was located again in 1905 by Captain Amundsen at a point a little farther west, approximately 70° N. latitude, and 97° W. longitude, Fig. 429.

The location of the magnetic pole of the south was determined by Sir Ernest Shackelton at a point about 72° S. latitude and 155° E. longitude.

395. The Angle of Magnetic Declination. We sometimes say that the magnetic needle points north-south. This, how-

ever, is very rarely true. *True north from any point on the earth is the direction from that point to the north geographic pole.* Now the magnetic needle points to the magnetic pole, and as we have already learned, these two poles do not coincide. The angle made by the needle and true north is called the *angle of declination*. To find the angle of declination for a given place one may proceed as follows: Drive two stakes into the ground in such a position that a string stretched from one to the other will point to the North star, which determines very closely the direction of the north geographic pole. The string therefore lies on a geographic meridian; that is, it points true north-south. Now place a long magnetic needle just below the string. The angle made by the needle and the string is the angle of declination. The declination for Ann Arbor, Michigan, is at present very nearly two degrees, the needle pointing west of true north.

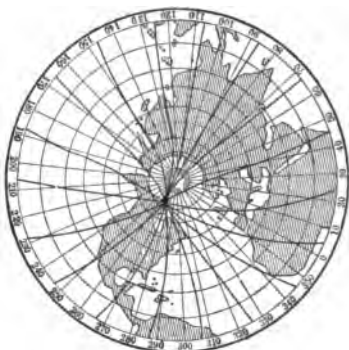


FIG. 429.—Magnetic pole of Northern Hemisphere

In some places the needle points to true north. A line drawn through such places is called a *line of no declination*. At present the line of no declination for the United States passes near Lansing, Michigan, Fort Wayne, Indiana, Cincinnati, Ohio, and Charleston, South Carolina. For all points east of this line the declination is toward the west; for points west of it, the declination is toward the east. The heavy line, Fig. 430, marked 0° , is the line of no declination for the Western Hemisphere.

396. Variation in the Direction of the Earth's Field. The magnetic poles are not fixed in position. The north magnetic pole, for example, swings slowly back and forth in an east-

west direction, requiring several centuries to make a complete vibration. This shifting of the magnetic poles, together with other causes not very well understood, gives rise to a continual variation in the angle of declination. In surveying

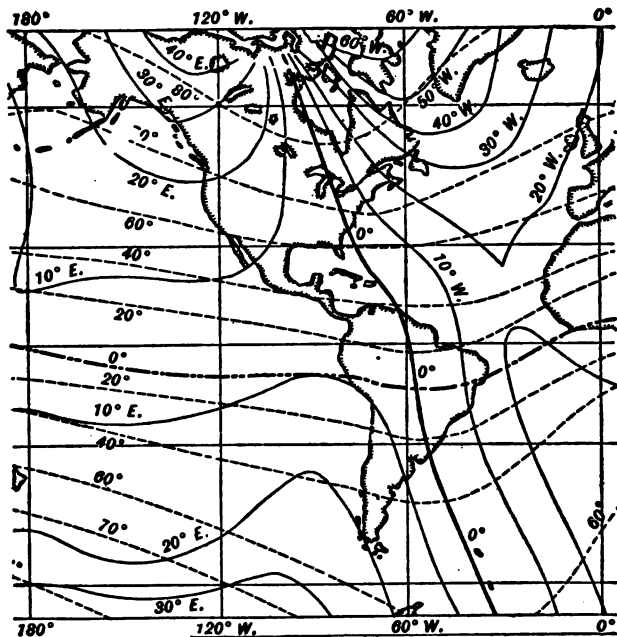


FIG. 430.—Line of no declination, Western Hemisphere

land it is very important that this variation shall be known. A systematic record, therefore, of all variations of terrestrial magnetism are made and kept by the United States government.

397. Magnetizing Effect of the Earth's Field. Since the magnetic lines of induction of the earth are sweeping constantly over its surface from the positive pole at the south to the negative pole at the north, all magnetic substances (iron and steel rods and bars especially) are more or less

affected. The fact is that all iron bolts and rods and bars, and especially those that lie in a north-south direction, are magnets, possessing N- and S-poles. This is true of the steel girders supporting our modern buildings and also of every steel ship that sails the seas.

The angle which the lines of induction of the earth's field makes with a horizontal line at any place on the surface of the earth is called the *angle of magnetic dip*. At the magnetic equator this angle is zero; that is, at the magnetic equator the dipping needle lies in a horizontal direction. As one goes north or south of the magnetic equator the angle of dip increases until at the magnetic poles it is 90° . At the north magnetic pole, for example, the dipping needle lies in a vertical direction. In the latitude of Ann Arbor the angle of dip is about 72° . This being the fact, it follows that iron bars, posts, telephone poles, flagstuffs, and other vertical objects which are made of iron or steel are magnetized in such a way as to cause the upper end (higher end) in each case to be an S-pole, and the lower end to be an N-pole. That this is true may easily be verified by testing the lower end of a steel post or rod with a small magnetic needle, such, for example, as that contained in a small compass. It will be found that the lower end of the metal post or rod repels the N-pole of the magnetic needle.

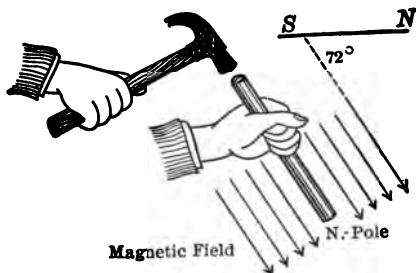


FIG. 431.—Magnetizing effect of the earth's field

A very interesting experiment to illustrate the magnetizing effect of the earth's field may be performed as follows: Take a bar of soft iron (a few feet of gas pipe will serve the purpose very well), which is as nearly demagnetized

as possible, and hold it in the earth's field, making an angle of about 70° with the horizon, as shown in Fig. 431. The lines of induction of the earth's field now enter the upper end and emerge from the lower end, thus tending to cause the lower end to become an N-pole. In order to hasten the magnetic action, strike the upper end a few sharp blows with the hammer. This jarring helps the molecules of the rod to orient themselves in response to the magnetizing influence of the field. Test the lower end of the rod. It will be found to be strongly magnetic, repelling the N-pole of the testing needle. Now reverse the rod and again strike the end with a hammer. The polarity of the rod is reversed; that is, the end which was an S-pole when placed downward in the field and subjected to the blows of the hammer soon becomes an N-pole.

In working in the laboratory with sensitive magnetic instruments great care must be exercised to guard against the magnetizing effect of adjacent magnetic substances, and account must also always be taken of the earth's field.

STATIC ELECTRICITY

398. Introductory. Phenomena associated with electrical discharges, as seen in the flash of lightning, have always been a part of man's experience, and in modern times the use of electricity in the production of light, the ringing of door bells, and the running of trolley cars has become so familiar as to excite no more wonder than the phenomena associated with gravitation, heat, or sound. There is one very important difference, however, between electrical phenomena and those of heat or sound. Take heat for example: we know not only what it does, but we also know what it is. In the case of electricity, on the other hand, we know what it does but we do not know exactly what it is. We know that electricity may reside upon a body in the form of a "static charge," and that it will "flow" from one body to another producing

a "current"; we know that the energy of a current of electricity may be transformed into heat, light, or mechanical motion, but just what electricity is no one at present is absolutely certain. Electricity is apparently neither matter nor energy; it may be combined or associated with matter, and energy may be expended in moving it. Indeed its great importance to mankind lies in the fact that energy expended upon it in one part of a system, as in the electric power plant, may be made to reappear in another part of the system in the form of light, heat, work, or chemical change.

We may therefore summarize as follows: (a) Electricity is not matter; it is associated with matter. (b) Electricity is not energy; we may expend energy upon it. (c) So far as we know electricity is indestructible; like matter and energy, it cannot be created or destroyed.

399. Electrification. Since the days of the ancient Greeks it has been known that when certain bodies were rubbed together they possessed the power of attracting other bodies. For example, if a glass rod be rubbed with silk it will attract a pith ball or bits of paper, Fig. 432. We say that the glass rod is electrified. In a like manner we may electrify a rod of sealing wax or vulcanite by rubbing it with flannel or cat's fur. Other familiar illustrations are seen in the electrification of a rubber comb when drawn through the hair, or in the electric discharge which occurs when the hand is drawn over a cat's back on a dry day.

A study of the phenomena of electrification is usually considered under that division of electricity known as static electricity. Electricity in a state of rest is called *static electricity*; electricity in motion, *current electricity*.



FIG. 432.—Bits of paper attracted by an electrified rod

400. Two Kinds of Electrification. It was early discovered that there were two kinds of electrification, one called positive (+), the other negative (-). (a) A glass rod rubbed with silk is said to be positively electrified. (b) A rod of sealing wax or vulcanite rubbed with flannel or cat's fur is negatively electrified. There are many other substances which may be electrified, some positively and some negatively. We shall, however, for the sake of simplicity and clearness, think of glass rubbed with silk as a type of positive electrification, and sealing wax or vulcanite rubbed with flannel or cat's fur as a type of negative electrification. We shall also speak of bodies as being charged positively when the charge is the same kind as that which resides on glass when rubbed with silk, and as being charged negatively when the charge is similar in kind to that on sealing wax or vulcanite when rubbed with cat's fur or flannel.

There appears to be no very good reason for calling the electrical charge on glass positive, or that on sealing wax or vulcanite negative, other than the fact that these terms were adopted when the subject was first studied.

401. Attraction and Repulsion. Among the most familiar phenomena of electrification are those of attraction and repulsion. If a rod be electrified and brought near a light body, such as a pith ball suspended by means of a fine silk thread, two things may be observed: (a) The pith ball is at first attracted to the electrified rod, and (b) after being in contact for a moment it is repelled. It is important to note that when an electrified body is brought near another body, attraction or repulsion always results.

The first law of repulsion and attraction may be demonstrated experimentally as follows: Charge a glass rod positively and suspend it in a stirrup, as shown in Fig. 433. (a) Bring near the suspended positively charged rod another glass rod also positively charged; the two repel each other. (b) Now present to the suspended positively charged glass

rod a vulcanite rod which is negatively charged; the two attract each other. The laws of attraction and repulsion may be stated as follows:

I. *Charges of like sign repel; charges of unlike sign attract.*

II. *The force of attraction or repulsion between two charges varies directly as the product of the charges, and inversely as the square of the distance between them.*

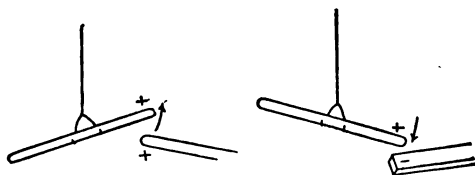


FIG. 433.—Charges of like sign repel; charges of unlike sign attract

III. *The force of attraction or repulsion between two charges depends upon the nature of the medium in which the charged bodies are placed.* For example, the force of attraction between charges of unlike signs is somewhat greater in a vacuum than in air; and the force of attraction is greater in the case of air as a medium than for glass.

402. The Electrostatic Field. The student will note the similarity of the laws of electrostatic attraction and repulsion to those of magnetism, as explained in Art. 386. It must not be assumed, however, that the phenomena of electrostatics are similar in all respects to those of magnetism; indeed, in certain respects quite the contrary is the case. For example, in the first place, (a) every magnet has two poles which remain near the respective ends of the bar, no matter what be the medium connecting them. No such permanent condition exists in the case of electrostatically charged bodies; electrostatic charges of opposite signs in a conducting body free from inducing charges always tend to flow together and thus neutralize each other. (b) The magnetic field about a

magnet is supposed to contain magnetic lines of induction emanating from the N-pole and entering the S-pole, forming closed curves throughout the entire circuit. The electrostatic field around a charged body, on the other hand, contains electrostatic lines of force which are conceived of as leaving a positively charged body and ending upon a negatively charged body. The condition of the electrostatic field about charged bodies is pictured in conventional diagrammatic fashion in Fig. 434. Here the sphere *A* is represented as having a + charge. The lines of force leave *A*, and a part of them enter *B*. The left hand end of *B*, therefore, has induced upon it a negative charge, while the right hand end has a positive charge.

The condition of the electrostatic field surrounding *A* and *B* (Fig. 434) is usually represented for convenience by the + and - signs, as shown by *A'* and *B'*.

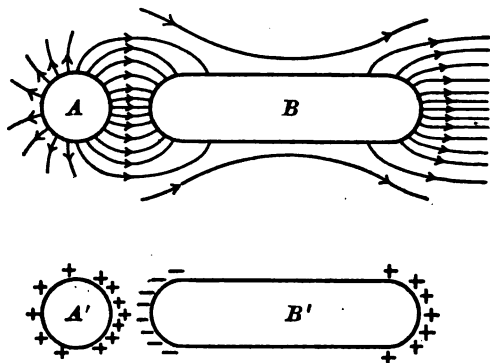


FIG. 434.—Electrostatic fields

403. Discussion of Attraction and Repulsion. We are now prepared to explain, in a measure, the phenomena of attraction and repulsion. If a glass rod positively charged be brought near a pith ball, Fig. 435, there will be induced on the side of the pith ball nearest the rod a - charge, and on

the side farthest from the rod a $+$ charge. The induced positive charge on the ball is exactly equal in quantity to the induced negative charge. Now since unlike signs attract and like signs repel, it follows that the $-$ charge will tend to move toward the glass rod and the $+$ charge away. The force of attraction, however, is greater than the force of repulsion, since the $-$ charge on the ball is nearer to the rod than is the $+$ charge. The moment the two come in contact, the negative charge on the ball is neutralized by some of the positive charge on the rod, and there remains on both rod and ball positive charges. Since charges having like signs repel each other, the ball is now driven away from the rod.

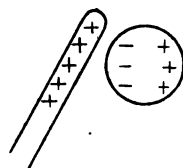


FIG. 435
Attraction and
repulsion

The above explanation of attraction and repulsion will apply whether the charging body has either a negative or a positive charge upon it.

The phenomena of repulsion between bodies having like charges may be demonstrated in a rather striking manner

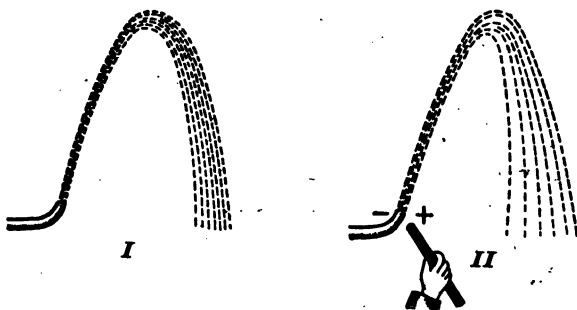


FIG. 436.—Electrical repulsion as illustrated by a spray of water

by means of a fine stream of water, as illustrated in Fig. 436. A fine stream which breaks up into a spray of droplets is made to issue from a nozzle. If a rod charged positively (say) is brought near the stream, the spray widens perceptibly. This

widening of the stream is due to the fact that the droplets of water have induced upon them negative charges, which repel each other.

404. The Two Kinds of Electrification Equal in Quantity. Experiments seem to prove that whenever a body is charged with electrification of one kind there is somewhere developed an equal charge of the opposite sign. Thus when a glass rod is rubbed with silk, a positive charge is developed upon the rod and an equal negative charge is developed upon the silk; similarly when sealing wax is rubbed with flannel, a negative charge occurs on the sealing wax and an equal positive charge upon the flannel.

To prove that positive and negative charges are always developed in equal amounts, Faraday used an ebonite rod upon which was fitted a flannel cap, Fig. 437. He electrified the two bodies by twisting the rod inside the cap and then removed the latter by means of a silk string attached to it. He tested both the charge upon the rod and that upon the cap and found that not only was the charge on the rod negative and that on the cap positive, but also that the two were exactly equal in quantity.



FIG. 437
Equal
charges

405. Charging by Conduction and Induction. A body may be charged electrically in two ways: by *conduction* and by *induction*.

(a) If a charged body be brought in contact with another body, some of the electricity on the first will flow off upon the second body. Thus the second body is said to be charged by *conduction*.

(b) If, on the other hand, the charged body be brought near a second body, there will occur upon the latter two charges equal in quantity and opposite in sign, Fig. 438. In this case the $+$ charge is said to be *bound*; the $-$ charge is *free*, and tends to get as far as possible from the

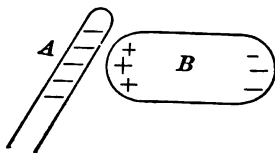


FIG. 438
Charging by induction

— charge on the rod. If a finger be touched to the charged body *B*, the free — charge will flow off. If now the charging rod *A* be removed, there will remain on *B* the + charge. *B* is then said to be charged by *induction*.

406. The Electroscope. An *electroscope* is an instrument for detecting the presence and kind of charges of static electricity. The electroscope consists of a metal ball or disc *D*, Fig. 439, attached to a metal rod *R*, to the lower end of which there is suspended two leaves of gold foil, *a* and *b*. The leaves of gold foil are enclosed in a case having glass sides. The use of the enclosing case is to protect the leaves of the electroscope from drafts of air or injuries from contact in handling.

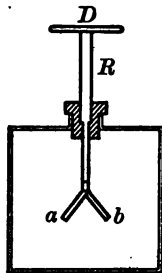


FIG. 439
Electroscope

A convenient and common form of electroscope is made by enclosing the metal foil leaves in a glass flask, as illustrated in sectional outline in Fig. 440.

407. How to Charge the Electroscope by Conduction. If a charged body be brought in contact with the electroscope, Fig. 440, some of the electricity will flow off the body onto the electroscope, distributing itself over the knob and leaves. The leaves of the instrument, being charged with electricity of like signs, will repel each other. When the charging body is removed it will have lost a quantity of electricity equal to that gained by the electroscope. *When an electroscope is charged by conduction the charge upon it is similar in sign to that on the charging body.*

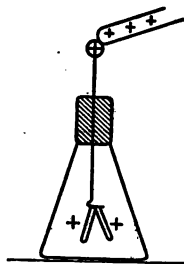


FIG. 440
Charging an
electroscope by
conduction

Sometimes it is desired to convey a definite portion of a charge to the electroscope. This may be done by means of a *proof plane*, which consists of a small metal

disc attached to a nonconducting handle, Fig. 441, and which is used to transfer small charges from one body to another.



FIG. 441
Proof plane

For example, if a proof plane be touched to a charged body, such as the pole of an electric machine, and then conveyed to the knob of the electroscope, a slight divergence of the leaves will result. Upon conveying a second charge a further divergence will occur. In this way it is possible to convey as much electricity to the electroscope as is desired.

408. How to Charge an Electroscope by Induction. Bring a charged body (positively charged, say) near the knob of the electroscope. There will be induced upon the knob a negative charge and upon the leaves an equal positive charge, Fig. 442 I. The negative charge is bound, and the positive charge free. Now if a finger be touched to the electroscope, Fig. 442 II, the free, positive charge, being repelled by the

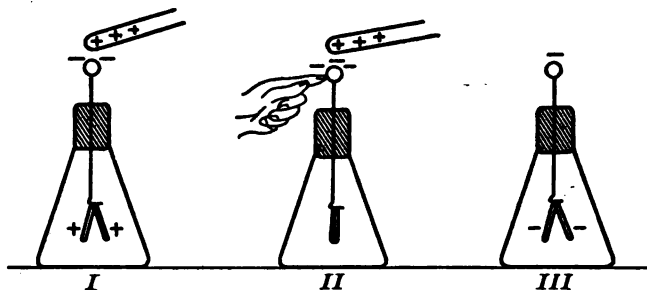


FIG. 442.—Charging an electroscope by induction

charge on the glass rod, will flow off to the earth. Remove the finger, and afterward remove the charging body. There will then remain upon the electroscope a negative charge which will distribute itself over the metallic part of the instrument. The electroscope is now charged by induction, Fig. 442 III. *When an electroscope is charged by induction, the charge upon it is of the opposite sign to that on the charging body.*

409. The Electrophorus. It is sometimes desirable to charge a body with a larger quantity than can be obtained upon a glass rod or a stick of sealing wax. To do this an *electrophorus* may be employed, Fig. 443. This consists of a shallow dish containing resin, sealing wax, vulcanite, or some similar non-conducting material. A metal disc of a size suitable to fit the dish is provided with an insulating handle.

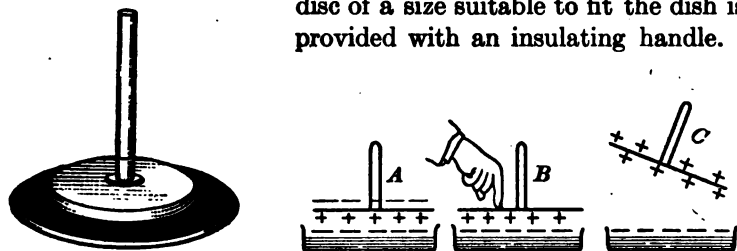


FIG. 443.—Electrophorus

To charge the electrophorus apparatus, we rub the non-conducting material with flannel or cat's fur, thus giving it a $-$ charge. If now we place the metal disc upon the surface of the apparatus, only a very small quantity of electricity will flow to the metal, because of the nonconducting property of the resin or other substance used. The $-$ charge on the resin induces $+$ charge on the under side of the disc and an equal $-$ charge on the upper side, Fig. 443 A. In this case the $+$ charge on the disc is bound, the $-$ charge is free. Now if the finger be touched to the disc, B, the free $-$ charge will flow to the earth, leaving behind the bound $+$ charge. The positively charged disc, C, may be removed and the charge on its surface conveyed to any other body.

410. The Electric Machine. An electric machine, Fig. 444, is nothing more than a device involving the principle of the electrophorus. It consists usually of one or more glass plates, which on being rotated become charged, mainly by induction. A cross metal bar serves to draw off the free electricity from

the rotating disc, and the bound charge is then transferred to the discharging points.

When the electric machine is in operation, that is, when the movable glass disc is caused to rotate about its axis, the

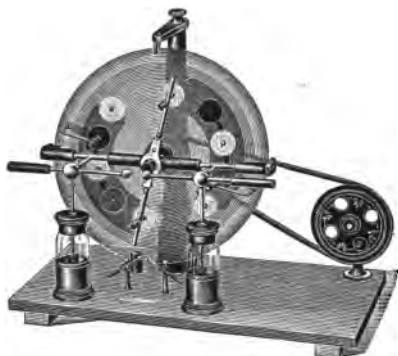


FIG. 444.—Electric machine

metal parts of the apparatus become highly charged; if these discharging knobs be brought close together a bright spark occurs. Should contact between the charged conductors of the machine be accidentally made by the hands of the operator, a severe shock will be received. To discharge the machine, bring the movable

metal knobs into contact by means of the insulating handles.

Many interesting and striking experiments may be carried out by means of the electric machine.

410a. How the Electric Machine Works. There are a number of different kinds of static machines, the most familiar laboratory types being the Toepler-Holtz and the Wimshurst machines. The machine illustrated in Fig. 444 is a Toepler-Holtz. The essential working parts of this machine is shown in outline in Fig. 445. There are two circular glass plates A and B, Plate A is stationary, and disc B is mounted so as to rotate about a central axis. On the back of the stationary Plate A there are pasted two strips of tin foil, C and D, which are called inductors. On the rotating disc there are pasted a series of circular carriers a, a', a'', a''' , made of tin foil. Each carrier has in its center a metal button designed to serve as a contact. Passing from one inductor to the other there is a metal rod E. The conductors which approach each other at P end in metal points at M and N, and communicate also with two small Leyden jars. Let us suppose that the machine is in action. Inductors A and B become charged to a certain extent, one positively and the other negatively. Sometimes this charging is done by touching one of the inductors with an electrified body; usually, however, the initial rotation of the

machine is sufficient to give the inductors a slight initial charge. Now as the disc rotates in the direction indicated, let us consider what happens to the carrier a . As it passes in front of the inductor A , it becomes electrified, the $-$ charge being bound, the $+$ charge free. The same thing happens on carrier a' , only in this latter case the $+$ is bound and the $-$ free. Now when the two carriers, a and a' , pass under the metal brush communicating with the metal rod E , the free $+$ charge on one neutralizes the free $-$ charge on the other. The carrier with its negative charge (a'') is carried on to the metal brush and conductor R . It is here transferred to the negatively charged inductor D . In a like manner the carrier with its positive charge (a''') is carried to the conductor R' , and thence to inductor C . Thus every rotation of the disc tends to charge the inductors C and D to a high potential, C with a $+$ charge and D with a $-$ charge. When these inductors become highly charged, a discharge takes place between the inductors and the metal points M and N , which communicate with the Leyden jars (Art. 411). When the charge on the Leyden jars becomes sufficiently great a discharge takes place across the gap at P . Thus it appears that the action of the machine is, in general, similar to that of the electrophorus.

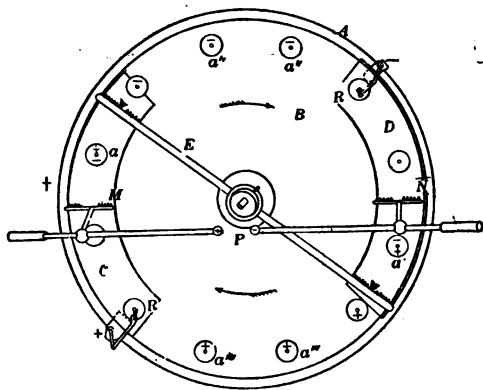


FIG. 445.—Essential parts of the Toepler-Holtz machine

411. The Leyden Jar. The *Leyden jar* consists of a glass vessel coated about two-thirds the way up on both the inside and the outside with tin foil, Fig. 446 I. A metal conductor communicates with the inner coating of the vessel. To charge

the jar we grasp the outer coating in the hand and place the knob in contact with one of the poles of an electric machine, thus charging the inner coating by conduction. The outer coating becomes charged through the glass by induction. Suppose, for example, that the inner coating of the jar have a $+$ charge, Fig. 446 *II*. Then the bound charge on the outside will be negative and the free $+$ charge will flow off from the hand to the earth.

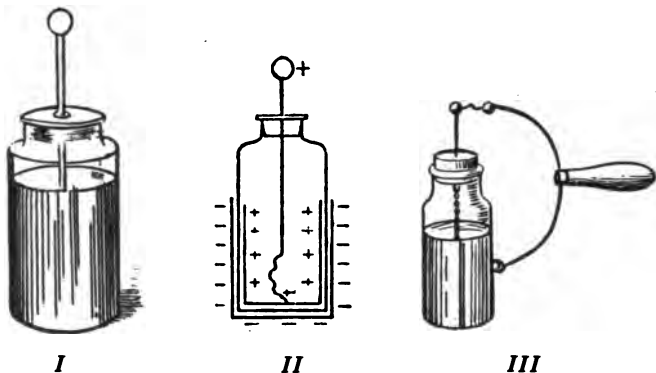


FIG. 446.—The Leyden jar

To discharge the jar a conductor having a glass handle is used, Fig. 446 *III*. Sometimes it is possible to obtain two or more sparks from the jar. This is due to what is called the residual charges. The glass when charged is supposed to be under a state of strain and does not entirely relieve itself on the first discharge.

Experiments with this piece of apparatus were first made at Leyden, Holland, in 1745, hence the name "Leyden" jar. According to the records, the experimenter was trying to "store up electricity" in a bottle partly filled with water. The electric charge was conducted from the knob of an electric machine to the water by means of a piece of wire which passed through the cork of the bottle to its liquid contents. The water served as the distributing inner coat of the vessel. The

walls of the bottle thus became charged. Holding the charged bottle in one hand the experimenter touched his finger to the conducting wire with the other. Immediately the Leyden jar was discovered.

412. Electric Pressure or Potential. We have learned that when a charged body *A* (a charged proof plane, for example) is brought in contact with an uncharged body *B* some of the charge on *A* is transferred to *B*. We have also learned in our experiments with the electric machine and the Leyden jar that when a conductor carrying a high positive charge is brought near a negatively charged conductor the transfer of electricity from one to the other takes place violently in the form of a spark discharge. Now there is a close analogy between the discharge or flow of electricity from one body to the other and the discharge or flow of water from one tank to another. Suppose for instance we have two tanks, as shown in Fig. 447, which are

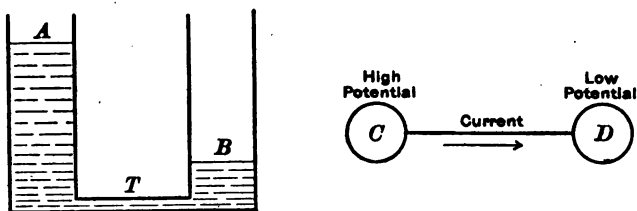


FIG. 447.—Analogy between hydrostatic pressure and electric potential

connected by a tube (water conductor) *T*. The water in tank *A* stands at a higher level than that in tank *B*. The water pressure (hydrostatic pressure) in *A* is greater than that in *B*, consequently the water flows through the tube *T* from *A* to *B*; that is to say, the water flows from a region of high pressure to one of low pressure. Or, to look at it in another way, if we find that the water flows from tank *A* to tank *B*, we are justified in saying that the hydrostatic pressure in *A* is higher than that in *B*. In a like manner if by means of a conductor (wire) we connect an electrically charged body *C* to a second

body *D*, and a transfer (flow) of electricity takes place from *C* to *D* we say that the electrical pressure (potential) of *C* is higher than the electrical pressure or potential of *D*.

In this connection two things should be borne in mind by the student. First, electrical pressure (so called) is only analogous to hydrostatic pressure; in certain respects electrical pressure is quite different from water pressure (Art. 432). And, second, while the term "electrical (or electric) pressure" is quite commonly employed, the more precise scientific term is *potential*. *Electricity always tends to flow from a point of high potential to one of low potential*. We sometimes speak of the earth as having zero potential.

The transfer of electricity through a conductor from a region of high potential to one of low potential gives rise to what is called an *electric current*. The subject of current electricity will be studied in detail later on.

413. Conductors and Insulators. Those substances which conduct electricity readily are classified as *conductors*; those which do not conduct electricity readily are known as *non-conductors* or *insulators*. An experimental classification of substances as conductors or insulators may be made as follows: (a) Connect the knob of an electroscope *E* to an insulated metal globe *G*, Fig. 448, by means of a fine copper wire.

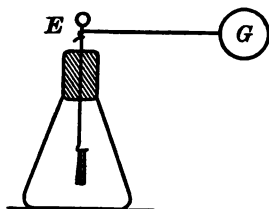


FIG. 448
Electrical conduction

Then by means of a proof plane convey a charge from the pole of an electric machine or other charged body to *G*. Instantly the leaves of the electroscope diverge, thus showing that a part of the charge imparted to *G* was conducted along the line to *E*. The copper wire is a good conductor of electricity. (b) Second,

remove the wire and connect *E* and *G* by means of a wet silk thread. Again charge *G* with the proof plane. The leaves of the electroscope diverge very slowly. A moist silk thread is

a poor conductor. (c) Finally, connect E and G by means of a dry silk thread, and charge G as before. The leaves do not diverge. The charge is not conveyed along the dry thread; dry silk is an insulator.

Metals, carbons, and solutions of salts in water are good conductors; on the other hand, glass, porcelain, rubber, mica, shellac, dry silk, vaseline, and oils are insulators. It should be noted, however, that no hard and fast distinction can be drawn between conductors and non-conductors. There are no substances which are perfect conductors and likewise there are no substances which are perfect insulators. The terms "conductors" and "non-conductors" are purely relative. The conductivity of all substances depends upon their physical condition, especially with reference to temperature and moisture. Glass, for example, at ordinary room temperature is a non-conductor or insulator; when heated to a temperature of 200°C , however, it becomes a conductor.

414. The Electrometer. An *electrometer* is an instrument for measuring potential. In its simplest form it is an electro-scope calibrated to give readings in terms of units of potential difference. A very effective form of electrometer, or electrostatic voltmeter as it is sometimes called, is shown in Fig. 449. The binding post A , which is carefully insulated from the circular metal case, is connected with the metal rod R , which in turn supports at its lower end a light aluminum vane L , mounted so as to swing freely in a vertical plane about its middle point. To the lower end of L there is attached a fine pointer which moves over the scale S .

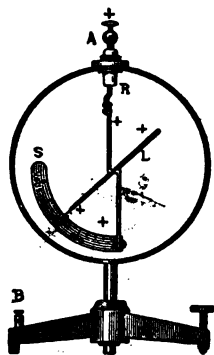


FIG. 449
Electrometer

Suppose that we wish to measure the potential of a body X having a positive charge of electricity. We proceed thus: First, by means of a fine wire connect X

with the binding post *A*. Then by means of a second wire connect the outer circular case of the instrument at *B* to the earth through the gas or water pipe system. Some of the charge on *X* flows through the conducting wire to *A*, and thence to the rod *R* and the vane *L*. The like positive charges repel, thus causing *L* to swing to one side into a given position, depending on the potential of the charge on *X*. The greater the potential of *X* the greater will be the deflection of *L*. The deflection of the pointer over the scale *S* indicates directly the potential of *X* with reference to the earth. Since the potential of the earth is taken as zero, and since the outer conducting case of the instrument is connected directly to the earth through *B*, the reading of the scale *S* gives directly the potential of the charge on *X*.

An instrument of this sort is very valuable for making potential measurements, first because of its comparative simplicity, and second because of the range over which readings may be taken. For example, by its use potential readings may be made from as low as 0.001 volt to over 100,000 volts.

Other methods of measuring potential difference (voltage) will be discussed in a later chapter.

415. Electrical Condensers. A *condenser* is a device by means of which the charge on a conductor may be increased without increasing the potential. A condenser enables one to obtain a large charge upon a body of convenient size.



FIG. 450
Electrical condenser

The modern commercial condenser consists of two or more sheets of tin foil separated by glass, mica, or paraffined paper, or other non-conducting substance, enclosed in a suitable case, Fig. 450. The conventional method of representing a condenser in diagrammatic outline is

illustrated in Fig. 451. Condensers are very largely used in the manufacture of induction coils (Art. 519) and in the

operation of many kinds of modern electrical apparatus, such as the telephone and the wireless telegraph.

The principle upon which the condenser works may be demonstrated by a very simple piece of apparatus, used in connection with an electrometer, Fig. 452. Fasten two metal conductors (sheets of tin, zinc or copper about a foot square) to wooden supports. Place the conductors *C* and *D* face to face about a foot apart. By means of fine wire connect the conductor *C* to the electrometer *A*, and the conductor *D* to the ground at *G*.

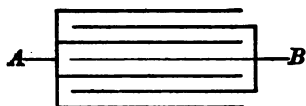


FIG. 451.—Diagram of a condenser

(a) With a proof plane charge *C* from an electric machine. The charge on *C* will induce a bound charge of the opposite sign on *D*, the free charge flowing through *G* to the earth. The vane *L* of the electrometer is deflected through a given angle, thus indicating the potential of the system. (b) Push *D* nearer to *C*, and it will be observed that the deflection of *L* diminishes, thus show-

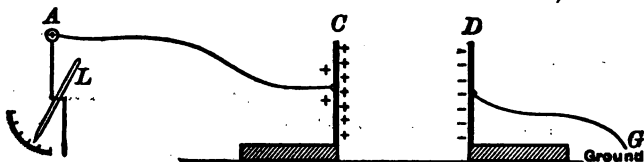


FIG. 452.—Testing the capacity of a condenser

ing that the potential of the system has been lowered. (c) Now add small charges to *C* until the deflection of *L* is the same as first observed. This means that by diminishing the distance between *D* and *C* we are enabled to increase the charge on *C* without increasing the potential above its original value. (d) Repeat the operation, adding a sufficient charge to *C* each time to bring the potential reading of the electrometer up to its initial value.

It thus appears that by means of two conductors *C* and *D* it is possible, by properly adjusting them, to vary the quantity

of electricity (charge) on the system without making a corresponding change in the potential. *It also appears that the capacity of the condenser is increased by bringing the plates nearer together.* The capacity of a condenser is numerically equal to the quantity of electricity required to change it to unit potential.

416. Static Charges Reside Upon the Surface. Place a tin cup or other hollow metallic vessel upon a nonconducting base of glass or paraffin and charge the cup from an electric machine. Touch a proof plane to the outside of the vessel and then to the knob of an electroscope; the leaves are affected, showing that there is a charge on the outside of the vessel. Now, touch the proof plane to the inside of the vessel and again to the knob of the electroscope; the leaves are not affected, showing that there is no charge on the inside. A static charge resides on the outside of a conductor. To prove that even for very high potentials the charge remains upon the surface, Faraday used a cage made of metal rods, inside of which he placed a sensitive electroscope. He then charged the cage so heavily that a spark discharge occurred from different points on the surface; the electroscope, however, was not affected in the slightest degree.

It has been found by many such experiments that a charge of electricity at rest, that is, static electricity, always resides upon the surface of the conductor.

417. Distribution of the Charge. The distribution of the charge of static electricity upon the surface of a conductor depends upon two factors: First, upon the shape of the conductor, and second, upon the presence or absence of other charged bodies.

In the case of a spherical conductor free from the influence of other bodies, the charge is distributed uniformly over the surface, Fig. 453. When there are present other charged bodies the charge is distributed somewhat as shown in Fig. 454. In the case of an irregular shaped body, the

charge has its greatest density at the pointed portion of the conductor, Fig. 455.

418. Influence of Sharp Points. Knowledge of the effect of sharp points in connection with conductors is of great importance in the operation of certain types of electrical apparatus. A sharp point serves to discharge the electricity upon a

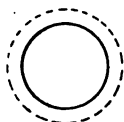


FIG. 453

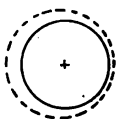
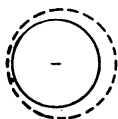
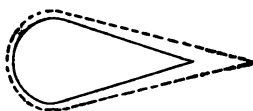
FIG. 454
Distribution of electrical charges

FIG. 455

body, as may be shown by the following experiment. If an electroscope be charged the leaves will remain apart for some considerable time, depending upon the condition of the atmosphere and the nature of the instrument. If now the head of a pin or other sharp pointed body fastened to the end of a glass rod be brought in contact with the knob of the electroscope, the leaves will collapse very quickly, thus showing the effect of the discharging point.

Small drops of moisture or particles of dust on electrical apparatus designed for use in electrostatics serve as discharging points. In order, therefore, to perform experiments with the electroscope, electric machine, or similar instruments, it is necessary that the apparatus be free from dust and that the experiments be performed when the air is dry.

419. Lightning. Benjamin Franklin was one of the first to demonstrate the similarity between the discharge of atmospheric electricity known as lightning and the discharge from a Leyden jar or an electric machine. During a thunderstorm he sent up a kite having a pointed wire at the top. The kite was provided with a hempen string, to the lower end of which was attached a key. In order to control the kite and at the same time to prevent the charge from passing through his

body, Franklin fastened to the kite string a piece of non-conducting silk ribbon, the end of which he held in his hand. When the hempen string became wet he succeeded in drawing from the key electric sparks which he concluded were similar in every respect to those that came from the Leyden jar. This experiment is a dangerous one, and cases are on record where experimenters have lost their lives in trying to repeat it.

When two clouds oppositely charged come near to each other the potential (electric pressure) may become so great that discharge takes place, resulting in a flash of lightning. The discharge from one cloud to another or from a cloud to the earth is similar in every respect to the discharge between the knobs of an electric machine, except that in the case of the atmospheric discharge the phenomenon occurs on a very much grander scale.

Observers sometimes imagine that they can see the flash of lightning go from one cloud to another, or from a cloud to the earth. This is, however, an optical illusion, since the discharge, as in the case of an electric machine or Leyden jar, is oscillatory; that is, the discharge occurs back and forth a great many times a second.

Thunder is the sound which accompanies a flash of lightning; it is caused by the sudden expansion of the air due to the flash. When a flash of lightning occurs the air along the line of discharge is heated, causing an increase in volume. This sudden expansion of the air gives rise to violent vibrations of the atmosphere, causing the crashing or rumbling noise called thunder. Thunder, therefore, always follows the flash of lightning and never precedes it.

In Fig. 456 there is given a reproduction of a photograph of a flash of lightning, showing foliage in the foreground and the illuminated heavens in the background.

420. The Lightning Rod. The lightning rod consists of a metal conductor provided with one or more sharp points, and having the lower end connected with the earth. The

exact use of the lightning rod as a protection for buildings has not, up to the present time, been thoroughly determined; it is believed, however, that its principal function is to furnish



FIG. 456.—Photograph of a flash of lightning, showing foliage in the foreground and the illuminated sky in the background

a means of silent discharge between the earth and the electrified atmosphere above, as illustrated by the principle of discharging points (Art. 418). An electrified cloud induces a charge of opposite sign on the earth and objects below it, a house for example, as shown in Fig. 457. If the building be provided with lightning rods the sharp points furnish a means of silent discharge, thus tending to keep the electric pressure below the striking potential. In some cases, however, even if lightning rods be present, the potential may be so high that a discharge occurs, in which case the rods may or may not protect the building from damage.

Damage done by lightning may be divided into two general classes: First, heat-effect damage, as, for example, where telephone or power conductors or other metal members lying in the path of the stroke are fused; second, mechanical dis-

ruptive disintegration, as, for example, the splitting of a tree, the breaking of a rock, or the overturning of a stack. Lightning seldom seriously damages such objects as railroad trains or locomotives, buildings with metallic-grounded sides and roofs, buildings having frameworks wholly of metal, grounded steel windmill towers, steel battleships, and business blocks in cities. Apparently all of these objects conduct electricity

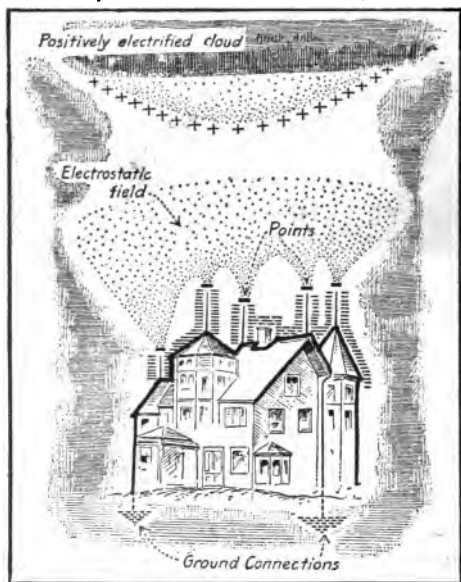


FIG. 457.—House protected by lightning rods

sufficiently well for electricity induced on them by a cloud to be dispersed by the point action before the difference of potential between the cloud and the object becomes great enough to produce a flash. If a lightning-stroke to such an object does occur, the mass of metal in it is usually sufficient to conduct the current safely to ground. Conversely, lightning often damages nonconducting objects such as country homes and

barns, wooden-frame school houses and churches, stacks, trees, cattle and horses, particularly where the stock is near wire fences. In general it is very dangerous for a person to seek refuge under a tree during a thunder storm.

It is now known that a lightning rod need not be made of any particular sort of metal or that it be of any special shape; heavy iron wire serves the purpose very well. The important facts to be kept in mind in installing lightning rods are (a) that the wires are to be so put up so as to furnish a number of discharging points at the top of the building, and (b) that the lower ends of the wires be buried deep enough so as to be in contact with moist earth.

421. Electric Screens. It is believed that the most effective protection from lightning is furnished by metal screens. This may be demonstrated by a simple device involving the principle of Faraday's celebrated screen experiment. Within a wire screen place a small electroscope and then put the apparatus thus formed between the knobs of an electric machine, Fig. 458. When the machine is operated a discharge takes place across the screen, during which the electroscope remains undisturbed.

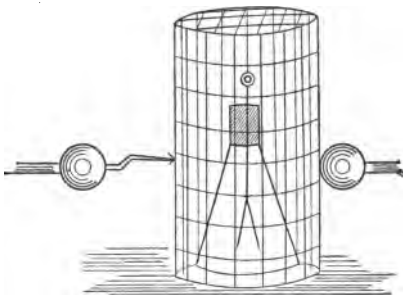


FIG. 458.—Electric screen

Warehouses and other buildings containing highly inflammable material are sometimes protected in this way by having stretched over them a network of metal conductors which are thoroughly grounded at a number of points. The screen effects of the metal roofs, girders, gas and water pipes which cover the modern structures of our cities probably explain why such buildings are so rarely injured by lightning.

422. Theories of Electrification. Phenomena attending electrification and electric discharge have always aroused man's interest and excited his curiosity. As was quite natural, scientists have sought to explain the observed facts associated with electricity by advancing theories as to its probable nature. We have, therefore, several theories relating to the nature and cause of the phenomenon known as electrification. These theories may for convenience be divided into two groups, namely, old theories and modern theories.

(a) Of the older theories there are two which deserve brief mention; these are the two-fluid theory, and the one-fluid theory. The practice of thinking and speaking of electricity as a fluid comes no doubt from the fact that electricity moves with apparent ease along conductors.

The two-fluid theory assumed that there were two electrical fluids, one of which was called positive and the other negative. It was generally agreed to call the charge found on glass when rubbed with silk positive, and the charge on sealing wax or vulcanite when rubbed with flannel or cat's fur negative. These terms (positive and negative) have been retained down to the present time. In all probability we shall continue to speak of the electrification generated on glass as positive and that on vulcanite as negative.

The one-fluid theory was advanced by Benjamin Franklin. According to this theory a body is positively charged when it has an excess of the electric fluid, and is negatively charged when it has upon it a deficiency of the electric fluid. Franklin represented the condition of positive electrification by the plus (+) sign and that of negative electrification by the minus (-) sign.

(b) Modern researches, however, go to show that neither of the fluid theories are satisfactory. The theory which is commonly accepted by scientists today is embodied in what is known as the electron theory. The details of this theory will be presented in the article which follows.

423. The Electron Theory. Extended researches made in recent years teach us that there are two kinds of electricity, positive and negative. Of negative electricity we have learned many definite things; of positive electricity, on the other hand, we as yet know very little. We have every reason to believe that associated with every atom of matter there are both positive and negative charges. The negative charge consists of tiny corpuscles which are called electrons.

An *electron* consists of a negative charge of electricity; it is the smallest particle known to science.

It is assumed that in every atom there is a positively charged nucleus, around which there is grouped a number of electrons, which are conceived to be in constant motion. In a neutral atom, the amount of the positive charge is assumed to be just equal to the sum of the negative charges. When an atom or group of atoms contains an excess of electrons it is negatively charged; and conversely, when an atom has a deficiency of electrons, that is, not enough to neutralize the positive nucleus, it is positively charged.

According to this theory, then, in order to charge a body negatively we must operate in such a way as to give it an excess of electrons, and in order to charge a body positively we must take electrons from it. This means that when we charge a glass rod positively by rubbing it with silk, for example, we take from the glass electrons which cling to the silk. The glass thus becomes positively charged and the silk negatively charged.

424. Known Facts Relative to Electrons. The following facts have been well established with reference to electrons: (a) *Mass.* The electric mass of the electron has been accurately determined. Each electron has a mass which is $\frac{1}{1845}$ of the mass of the hydrogen atom. (b) *Speed.* The speed with which an electron travels under given conditions has been determined for different conditions. For example, the speed of an electron in an evacuated tube may be as great as 100,000

miles per second, that is, a little more than one-half the speed of light (Art. 325). (c) *Electric charge*. All electrons carry the same electric charge, both with reference to kind (—) and amount. The charge of an electron is called the elementary electric charge. The total charge on every electrified body is equivalent to an exact number of these elementary charges. (d) *Behavior in magnetic and electric fields*. A stream of electrons may be deflected by a magnet. Also, electrons are attracted by positively charged bodies and repelled by negatively charged bodies.

A current of electricity may be conceived of as nothing more than a stream of electrons moving from one region to another through a conductor.

REVIEW EXERCISES

1. (a) What is a natural magnet? magnetic substances? magnet?
(b) What is the distinction between a magnetic substance and a magnet?
2. Define: (a) N-pole of a magnet, (b) S-pole, (c) magnetic axis.
3. A steel knitting needle is drawn several times across the S-pole of a bar magnet. (a) Which is the N-pole of the needle thus magnetized?
(b) Why should the needle be drawn across the pole of the bar magnet always in the same direction?
4. State the three laws of magnetic attraction and repulsion.
5. Two like magnetic poles, m and m' , 2 cm apart, repel each other with a force of 4 dynes. With what force will they repel each other when they are 4 cm apart?
6. Suppose that the pole strength of m (problem 5) be doubled and the pole strength of m' be quadrupled. With what force will they now repel each other when they are 2 cm apart?
7. Given two small cylindrical pieces of iron, AB and CD . One is soft iron and the other is a permanent magnet. By means of a bar magnet you are required to determine which of the pieces (AB or CD) is a magnet?
(a) When the N-pole of the bar magnet is presented to the end B of the first piece, attraction occurs; likewise when the S-pole is presented to B , attraction again occurs. What is the piece AB (magnetic substance or magnet)?
(b) When the N-pole is presented to the end D of the second piece attraction occurs; and when the S-pole is presented to D , repulsion occurs. What is CD ?

8. In testing a needle with a magnet to determine if the needle is a magnet, why must you get repulsion before you can say definitely whether or not the needle is a magnet?

9. (a) Define magnetic field; magnetic line of induction. (b) Out of which pole of a magnet are the lines of induction assumed to come? (c) Trace by means of a sketch the complete path of a given line of induction.

10. Make a sketch to illustrate the magnetic field between (a) like poles; (b) unlike poles.

11. (a) What is a magnetic transparency? Name some substances that are magnetically transparent. (b) Explain how a ring of soft iron may be used as a magnetic shield.

12. (a) When a bar of iron is magnetized how are its molecules supposed to be affected? (b) Why does heating or dropping a magnet tend to diminish its polarity?

13. (a) What evidence have we to prove that the earth is a magnet? (b) Where is its N-pole? its S-pole? (c) Are the magnetic poles stationary?

14. (a) Define angle of declination. (b) Explain how one may find the angle of declination at a given place.

15. What is the line of no declination? If a person is east of this line how will a compass needle point with reference to the north geographic pole? What is "true north" from a given place?

16. What is magnetic dip? What is the value of the angle of dip (a) at the magnetic equator? (b) at the magnetic pole?

17. An iron bar is left lying for some time in a north-south direction. How will the north end of this bar affect the N-pole of a compass needle?

18. The S-pole of a magnetic needle when brought near the top of a steam radiator is repelled. Explain.

19. What is the effect of near-by deposits of iron ore, iron posts, wire fences and the like upon the surveyor's compass?

20. (a) What electric charge is developed on glass when rubbed with silk? (b) What change is developed on vulcanite when rubbed with flannel?

21. A rod of sealing wax negatively electrified is brought near a small spherical conductor. (a) Show by drawing what happens on the sphere? (b) When the electrified rod is removed what happens to the two charges on the conductor?

22. An electrified rod is brought near a pith ball; the ball is first attracted and then repelled. Explain.

23. State the laws of electrostatic attraction and repulsion.

24. What is the distinction between static electricity and current electricity?

25. Explain how to charge an electroscope by (a) conduction, (b) induction.

26. Given a glass rod and a piece of silk, explain two ways of getting a negative charge.

27. Explain how to charge a body by means of the electrophorous apparatus. What is the object of touching the fingers to the disc before removing it from the lower plate?

28. Show by means of a sketch the various charges which reside on a Leyden jar when the knob of the jar is charged negatively by conduction. When the jar is thus charged what happens when the outer coat is touched by the hand, or otherwise connected to the earth?

29. Explain the analogy between hydrostatic pressure and electric pressure or potential.

30. A charged body of high potential is connected by means of a wire to a body of low potential. What happens in the wire?

31. Define: (a) conductor, (b) insulator. Give examples of each.

32. Explain how temperature and moisture may affect the conductivity of a substance.

33. Wherein does an electrometer differ from a simple electroscope? For what is an electrometer used?

34. What is a condenser, and for what is it used? Of what are the conducting sheets of commercial condensers made? What dielectrics are employed?

35. A Leyden jar is a condenser. In charging a Leyden jar by connecting the knob of the jar with the knob of an electric machine, why should the outer coat of the jar be held in the hand, or otherwise connected with the earth?

36. A body is charged, either positively or negatively. Explain why the charge resides upon the surface.

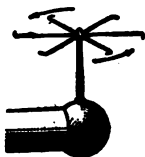


FIG. 459

37. Make a drawing to illustrate the distribution of a charge (a) on an isolated sphere; (b) on two adjacent spheres; (c) on a body of irregular outline.

38. An "electric whirl" when mounted upon or otherwise in electrical contact with the charged knob of an electric machine will spin around, as illustrated in Fig. 459. Explain.

39. (a) What is lightning? (b) thunder? (c) Which is the cause of the other? (d) What did Franklin prove by the kite experiment?

40. How does a lightning rod protect a building? Wherein is the discharging action of points exemplified by the rod?

41. (a) What is an electric screen, and what practical use is made of it? (b) How explain the fact that the modern skyscraper of our cities is so rarely damaged by lightning?

42. (a) What is an electron? (b) Are atoms supposed to contain both positively and negatively charged particles? (c) What charge does the nucleus of the atom carry?

43. According to the electron theory, when is a body (a) negatively charged? (b) positively charged? (c) neutral?

44. State and discuss briefly four facts which have been definitely determined with respect to electrons.

45. In the light of the electron theory, define electric current.

CHAPTER X

CURRENT ELECTRICITY

THE VOLTAIC CELL

425. Introductory. A *voltaic cell* is a device for transforming the energy of chemical action into the electrical energy of a current. The lighting, heating, and magnetic effects of electric currents are so commonly met with in everyday life that they no longer excite either comment or wonder. We press a button and the electric light comes on; we turn a switch and the electric flatiron gets hot, or the electric oven is heated; we throw a lever and the electric motor runs, driving machines in our factories, propelling the cars upon our streets, and operating such household devices as the vacuum cleaner, the electric fan, or the sewing machine. Electrical appliances are today everywhere present, and yet it should not be forgotten that they are of comparatively recent origin. As is true of the development of all sciences from the theoretical to the practical, so, too, in this branch of physics scientists had to study for many years the phenomena associated with electrification, the construction of electric cells, and the nature and effects of electric currents before it was possible to make practical applications of the laws and principles discovered.

While observations on electrostatic phenomena were made and recorded as early as 600 B. C., it was not until 1786 A. D. that it was discovered that an electric current could be produced by chemical action. This important discovery was made by Galvani, an Italian anatomist of Bologna, while preparing frogs' legs for dissecting purposes. The legs and part of the body of a freshly killed frog were suspended by means of a copper wire from the iron frame of a porch in front of his house. The wind caused the moist tissue of the frog

to come into contact with the iron frame, thus completing an electric circuit between the frog's legs and the metals, iron and copper. The experimenter noticed that at the instant of contact with the iron frame the frog's legs twitched spasmodically. He concluded that an electric current was generated in some way at a point in the circuit including the iron, copper, and the moist tissue. For a long time after this an electric current which gave rise to convulsive muscular action was known as "galvanic electricity." We now know of course that the so-called galvanic electricity does not differ from electricity in general.

That the phenomenon observed by Galvani was caused by a current produced by chemical action was not known for a certainty until 1800, when another Italian scientist named Volta constructed the first electric cell. The term "voltaic cell" was later chosen in honor of Volta.

426. The Simple Voltaic Cell. A voltaic cell such as is frequently used for laboratory experimentation is shown in Fig. 460. Such a cell consists of strips of copper and zinc partly immersed in a dilute solution of acid in water. The cell is set up as follows: Into a dilute solution of sulphuric acid place a strip of copper and a strip of zinc, so that they are a few centimeters apart. The copper becomes positively electrified and the zinc negatively electrified. If now the copper and zinc be connected by means of a wire, a current will flow through the circuit, as may be demonstrated by the deflection of the needle of a galvanometer or the ringing of an electric bell when the terminals of these instruments are connected in the external circuit, as at *G*.

This combination of copper, zinc, and acid constitutes what is known as a *simple voltaic cell*. The essential parts of a simple



Alessandro Volta

voltaic cell are two metals and a solution, the metals to be of such a nature that the solution acts upon one of them more readily than upon the other.

427. Terms Used in Connection with the Electric Cell. The solution used in a voltaic cell is called the *electrolyte*. The two metals are the *electrodes*. That portion of an electrode which is immersed in the solution is sometimes called the

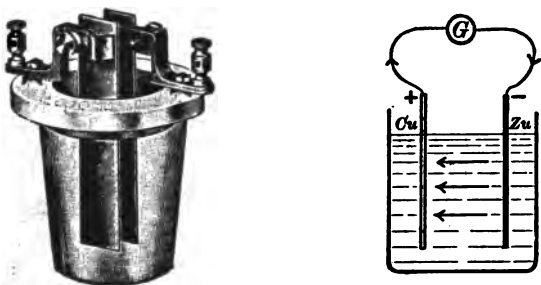


FIG. 460.—Simple voltaic cell

plate, and the portion to which the wire is attached, the *pole*. The electrode which becomes positively charged is the *positive electrode*; the one negatively charged, the *negative electrode*. The electrode which is least affected chemically is usually the positive electrode; the one most affected chemically, the negative electrode. For example, in the case of the cell described in the preceding topic, the copper is the positive electrode, the zinc the negative. The entire path of the current is called the *circuit*. That part outside the liquid is the *external circuit*; the part within the liquid, the *internal circuit*.

When we turn on, or otherwise close a switch so that the current in the system flows uninterruptedly, we then speak of the circuit as a *closed circuit*. A telegraph system operates on a closed circuit, the current flowing practically all of the time. In a door bell system, on the other hand, the current flows only at irregular intervals, that is, when someone closes the circuit by pressing upon the push button. The door

bell circuit is open most of the time; such a circuit is called an *open circuit*.

An *electric battery* consists of a number of cells joined together.

428. Charges on the Electrodes. When electrodes such as copper and zinc are immersed in an electrolyte, the copper becomes positively charged and the zinc negatively charged by the chemical action which takes place in the cell. The signs of the charges on the respective electrodes of a cell may easily be determined by means of a sensitive electroscope. Use is made of an electroscope which has upon the upper end of the conductor carrying the gold leaves a circular metal disc, 6 or 8 centimeters in diameter, Fig. 461. A second and similar disc is provided with a glass insulating handle. Place one disc upon the other, separating them from each other by means of a sheet of paper, or better, a thin sheet of mica. The two discs so placed constitute a condenser (Art. 415). By

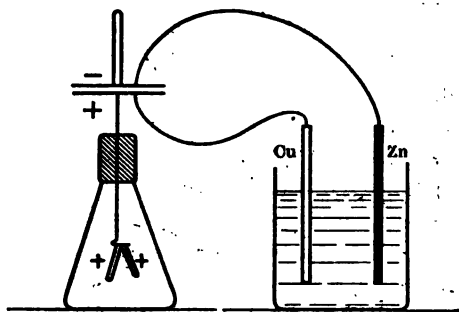


FIG. 461.—Positive charge on copper; negative charge on zinc

means of wires connect one electrode to the lower disc and the other electrode to the upper disc, as shown. A charge of one sign flows from the cell to the lower disc, and a charge of opposite sign appears upon the upper disc. Now remove the wires and then remove the upper disc. The charge which was "bound" upon the lower disc by the opposite charge upon the upper disc now being free, distributes itself over the conducting systems of the electroscope, thus causing the leaves to diverge. To test the charge upon the leaves, touch the

top of the electroscope with a proof plane carrying a known charge (a positive charge from glass, for example). If the leaves fly farther apart we know that the charge imparted to them from the electrode of the cell is positive; if, on the other hand, the leaves fall nearer together then we know that the charge upon the electrode is negative. By means of a test such as just described we learn that the charge on the copper electrode is positive and that on the zinc is negative.

429. Direction of the Current. In accordance with long established custom, we have been taught to think of the current as flowing in the external circuit from the positive electrode to the negative electrode, that is, in the case just given, from the copper to the zinc.

In view of the modern electron theory, however, in which we think of a current as a stream of electrons, we meet with a difficulty. In fact the practice which was adopted in early times of speaking of a current as flowing from positive to negative turns out to be embarrassing and somewhat unfortunate, as the facts now show. For, since the zinc electrode is negatively electrified it must therefore contain an excess of electrons, and conversely, the positively charged copper electrode must have a deficiency of electrons, as explained in Art. 423. Since, therefore, an electric current, according to modern notions, is considered to be a stream of electrons flowing through a conductor from a region having an excess of electrons (negatively charged zinc electrode) to one having a deficiency of electrons (copper) it follows that, according to the electron theory, the current really flows through the metal conductor from the negative electrode to the positive, that is, from the zinc electrode through the wire to the copper electrode.

This question, therefore, naturally presents itself: Is it desirable or necessary to change our notation with respect to the direction of flow of a current? Since in practically all our literature a current is represented as flowing from the positive electrode to the negative, and since this conception is today

familiar to the great majority of those who have studied and are using electrical currents, would not such a change in the manner of our representation of the direction of flow of a current bring about needless and unnecessary confusion? Such is probably the case. In this text, therefore, while we shall think of a current as a stream of negatively charged particles called electrons, we shall, for the sake of clearness, as is quite in accord with good modern authority, continue to speak of, and to represent diagrammatically the current as directed in the external circuit from the positive electrode to the negative electrode. Such representation need not in any way be misleading, provided we keep in mind the facts relating thereto.

430. Voltaic Cells with Different Electrolytes. It must not be supposed that in order to make a voltaic cell it is necessary to use a dilute solution of sulphuric acid, as the electrolyte. Any solution, be it acid, base, or salt, which will act chemically upon the one electrode more readily than upon the other, will serve as an electrolyte. This may be shown by the following experiment. Use electrodes of copper and zinc, connecting the poles to a galvanometer. Dip these electrodes successively into the following solutions, rinsing the electrodes in water after each test: (a) dilute sulphuric acid; (b) dilute hydrochloric acid; (c) dilute acetic acid (vinegar); (d) solution of sodium chloride (NaCl). In each case the galvanometer is deflected, showing that a current is set up by the cell. If the electrodes be thrust, for example, into an apple, Fig. 462, a current will also flow, due to the action of the juices of the apple upon the metals. In fact almost any vegetable will act chemically upon the zinc sufficiently to set up a current.

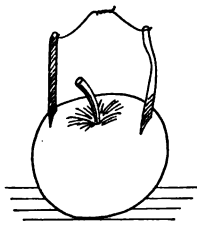


FIG. 462
An apple cell

431. Voltaic Cells with Different Electrodes. In this experiment it is desired to show that different substances may be

used as electrodes. Take as the electrolyte a dilute solution of sulphuric acid. First, use as electrodes copper and zinc. The copper, as we have seen, is positive to the zinc, causing the pointer of the galvanometer to be deflected in a given direction. Second, use as electrodes copper and carbon. The current now flows through the galvanometer in the opposite direction; that is, from the carbon to the copper, as shown by the opposite deflection of the pointer. The copper is in this case the negative electrode. By similar experiments it may be shown that copper is positive to zinc and iron, but is negative to silver, platinum, and also, as has been shown, to carbon. In the following list any element, copper for example, is positive to the elements on the left of it and is negative to elements on the right:

— Zn Fe Cu Ag Pt C +

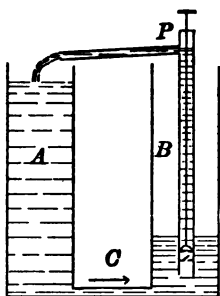


FIG. 463
Analogy between
hydrostatic pressure
and e.m.f.

Thus iron is positive to zinc and negative to copper, while copper is positive to iron, but negative to silver. The farther any two elements in the list are removed from each other, the greater is the terminal potential difference of the cell. In most commercial cells zinc and carbon are used as electrodes.

432. Potential Difference and Electromotive Force. The student is already familiar with the idea that currents of electricity flow from points of high potential to those of low potential in a manner analogous to the flow of water from a point of high pressure to one of low pressure. Let us suppose that the water flows from one tank to the other through the pipe C, Fig. 463, and that difference of level in the two tanks is maintained by the operation of the pump P. We may consider such a system as somewhat analogous to

that of an electric cell, the difference in pressure between *A* and *B* corresponding to the difference of potential between the electrodes of the cell. In the case of the water the difference of level is maintained by the expenditure of energy through the agency of the pump; in the electric cell the difference of potential is maintained by the expenditure of energy due to chemical action.

Electromotive force (e.m.f.) of a voltaic cell is that which tends to produce a current. The e.m.f. of a cell is equal to the difference of potential between the electrodes when the circuit is open; it is also equal to the fall of potential around the entire circuit when the circuit is closed. Electromotive force may be measured directly by means of an electrometer or electrostatic voltmeter, as explained in Art. 414. Connect one electrode of the cell to terminal *A*, of the electrostatic voltmeter, Fig. 449, and the other electrode to terminal *B*. The instrument if properly calibrated gives the e.m.f. of the cell in volts.

In connection with electromotive force it is important to note two things: (a) While we speak of electric pressure as being *analogous* to water pressure, it must be borne in mind that *electromotive force is not force*, nor is it measured in units of force; *e.m.f. is measured in units of work (ergs) per unit quantity of electricity conveyed around the circuit*. (b) In the second place, a voltaic cell does not generate electricity; it generates electromotive force. The cell does not generate electricity any more than the pump of Fig. 463 generates water.

The greater the electromotive force of a cell the greater the current will it furnish through a given conductor. The unit of current strength is the *ampere* (Art. 454), the unit of electromotive force and potential difference is the *volt* (Art. 456).

433. Local Action. If a strip of commercial zinc be placed in a dilute solution of sulphuric acid, chemical action at once takes place. The zinc is dissolved, forming zinc sulphate and

liberating hydrogen. The reaction may be written $\text{Zn} + \text{H}_2\text{SO}_4 = \text{ZnSO}_4 + 2\text{H}$. This chemical action is called *local action*; it is due to impurities in the zinc in the form of tiny particles of carbon, iron, etc. Each particle constitutes, with the zinc and acid, a voltaic cell, Fig. 464. If the zinc were perfectly pure there would be no local action. Local action is detrimental because it represents a useless waste of zinc, giving rise to chemical action, but furnishing no useful current to the circuit. It may be prevented by coating the zinc plate with mercury; that is, amalgamating the zinc.

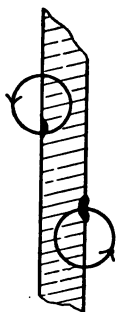


FIG. 464
Local
action

To demonstrate the effect of amalgamating the zinc plate, take a strip of commercial zinc and after cleaning it by immersing it for a few moments in dilute sulphuric acid, rub mercury over its surface until the latter becomes bright and mirror like. The impurities in the zinc are then covered by the mercury, which not only spreads over to every part of the surface of the plate but also penetrates to a considerable depth. If the amalgamated plate thus formed be now placed in the acid, no chemical action will occur, so long as the zinc is not a part of the electrical circuit of the cell. If, however, the amalgamated zinc plate be connected to the copper electrode by means of a wire, chemical action will at once take place between the acid and the amalgamated zinc, all the energy being now used to furnish a current. Thus it appears that amalgamating the zinc plate prevents local action, but at the same times does not hinder in any way the zinc from acting as the negative electrode when connected with the positive electrode by means of an external circuit.

434. Polarization. If we close the circuit of a simple voltaic cell consisting of dilute sulphuric acid and electrodes of copper and amalgamated zinc, bubbles of hydrogen will appear in large numbers on the copper electrode. This appearance of

hydrogen on the positive electrode does not mean that the copper is being dissolved by the acid; it does mean that the hydrogen from the electrolyte is transferred during the operation of the cell from the solution to the positive electrode, upon which it forms a gaseous layer. This collection of hydrogen on the positive electrode reduces the e.m.f. of the cell, thereby cutting down the current. When in this condition the cell is said to be polarized.

Polarization is the reduction of the e.m.f. of a cell, due usually to the collection of hydrogen on the positive electrode.

Polarization is detrimental because it reduces the e.m.f. of the cell. It may be remedied by adding to the electrolyte an oxidizing agent; that is, a substance which will furnish oxygen to unite chemically with the hydrogen on the electrode and thus form water, as represented by the chemical equation



One of the most desirable oxidizing agents for depolarizing purposes is a solution of chromic acid. Next in importance is a solution of sodium bichromate. Potassium bichromate is sometimes used; it is not so satisfactory, however, as the sodium bichromate on account of the insoluble crystals which it forms.

435. Factors that Determine the E.M.F. of a Cell. The electromotive force of a cell is determined by three factors: (a) the kinds of electrodes used, (b) the nature of the electrolyte, and (c) the temperature at which the cell operates. *The e.m.f. is independent of the size of the plates.* A cell of given materials, such for example as zinc, copper, and dilute sulphuric acid, no larger than a lady's thimble will furnish as high an e.m.f. as will a similar cell having a volume capacity of several gallons. While the e.m.f. of a cell is independent of its size, nevertheless a large cell is, in general, more desirable than a small one, because the larger the cell the less the resistance, and hence the greater the current, and also the larger the cell the longer will its material last to furnish a current.

KINDS OF CELLS

436. Introductory. There are many different types of cells, depending on (a) their form, (b) the character of the electrodes, and (c) the nature of the electrolyte. In this text only a few of the more common types will be considered, namely, the gravity cell, the Leclanché cell, and the dry cell.

So far as the consumption of energy is concerned as compared with the useful work performed, the voltaic cell is a rather wasteful engine. Wet cells, that is, voltaic cells having as an electrolyte a solution of an acid, base, or salt, are gradually being driven out of use as current producers by the more convenient "dry cell" and especially by the electric generator (dynamo).

437. The Gravity Cell. A form of the *gravity cell* is shown in Fig. 465. The positive electrode consists of a piece of copper,

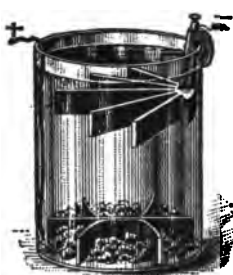


FIG. 465
Gravity cell

Cu, placed at the bottom of the cell. The negative electrode is a piece of zinc, Zn, of the crowfoot form, suspended from the upper margin of the battery jar. The wire leading from the copper electrode to the pole must be well insulated.

The cell is set up as follows: Crystals of copper sulphate are placed in the bottom of the battery jar, which is then filled with water. A few drops of sulphuric acid are added to the water in contact with the zinc. This acid reacts upon the zinc, forming a dilute solution of zinc sulphate, which being lighter than copper sulphate remains near the surface. We thus have in the battery two different solutions; namely, a saturated solution of copper sulphate in contact with the copper plate, and a dilute solution of zinc sulphate in contact with the zinc plate. Batteries of this type are called two-fluid batteries. When the cell is in action zinc dissolves from the negative plate and goes into solution; copper from the electrolyte goes out of solution and is deposited upon the copper plate. Thus

the zinc plate grows lighter as the cell continues in use, and the copper plate grows heavier. Since there is no hydrogen involved in the operation, no polarization occurs. *Herein lies the great advantage of cells of this type, namely, they do not polarize.* The gravity cell is used where continuous currents are desired, as, for example, in the *closed circuit work* of telegraphy.

The *Daniell cell* is another type of the two-fluid battery, differing from the gravity cell only in form. The copper sulphate is placed in the outer chamber of the cell; the zinc plate and zinc sulphate solution, in the inner chamber, which consists of a porous cup.

The e.m.f. of both gravity and Daniell cells is about 1 volt.

438. The Leclanché Cell. This cell consists of a vessel, as shown in Fig. 466, which contains a solution of ammonium chloride. A rod of carbon serves as the positive electrode; a rod of zinc, as the negative electrode. The positive carbon electrode is placed in a porous cup which is filled with a mixture of graphite and manganese dioxide. The function of the manganese dioxide is to serve as the depolarizing agent.



FIG. 466
Leclanché cell

This cell is used for *open circuit work*, such as the ringing of door bells. The e.m.f. of the Leclanché cell is about 1.4 volts.

439. The Dry Cell. The so-called dry cell, Fig. 467, is a modified form of the Leclanché cell. In reality it is not a dry cell at all, since it contains a moist paste consisting of ammonium chloride, zinc chloride, zinc oxide, and plaster of Paris. The e.m.f. generated is due to the action of the ammonium chloride upon the zinc electrode, which in this case forms the outer wall of the cell. The positive electrode is a carbon rod. The cell is hermetically sealed to prevent evaporation.

When the dry cell is new its current-producing power is high; with time, however, its internal resistance increases and its current is cut down proportionally.

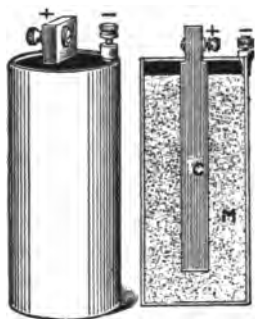


FIG. 467.—Dry cell

On account of the cheapness and convenience of these cells they are today more extensively used than any other type, many millions being manufactured and sold annually. Where storage batteries are not available in connection with the operation of various types of the gas engine, and for use in flash lights and in telephone service, the dry cell as a source of electromotive force and current is relatively cheap, convenient, and very effective.

The e.m.f. of the dry cell is about the same as that of the Leclanché cell, namely, 1.4 volts.

CHEMICAL EFFECTS OF A CURRENT

440. Introductory. We have learned from our study of the voltaic cell that when the circuit is closed, the current which flows in the external conductor from the positive electrode to the negative electrode completes the circuit from electrode to electrode through the electrolyte. That is to say, part of the path traversed by the current is a solid conductor (metal electrodes and connecting wire) and part is a solution (the electrolyte). Now the mechanism by which the transfer of electricity takes place in the wire is quite different from that which is associated with the transfer of the electricity through the liquid of the cell. In the wire, transfer of electricity (current) is believed to be due to a stream of electrons which are more or less impeded in their motion by the intervening molecules of the metal. In the solution, on the other hand, we have every reason to believe that the electrical transfer is due to the bodily displacement of charged particles; in other

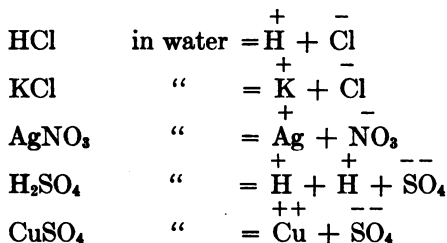
words, the electric charges are carried bodily from one electrode to the other through the solution by particles called "ions."

It thus appears that as a conductor of electricity an electrolyte, as compared with a metallic conductor, possesses certain distinctive and important features. In order to study the electrical conduction of electrolytes and the associated phenomena of electrolysis, we shall first have to learn something of the modern theory of solutions, as set forth in the dissociation theory.

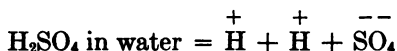
441. The Dissociation Theory. If a salt, such as sodium chloride (NaCl), be dissolved in water, the greater part of it *dissociates*; that is, it breaks up into parts called *ions*, as follows:

NaCl in $\text{H}_2\text{O} = \overset{+}{\text{Na}} + \overset{-}{\text{Cl}}$. The symbol for the sodium atom with a + sign above it, $\overset{+}{\text{Na}}$, is called the positive ion; $\overset{-}{\text{Cl}}$ is called the negative ion. The Na ion carries a positive (+) charge of electricity; the Cl carries a negative (−) charge of electricity.

The following chemical reactions illustrate a few of the simpler cases of ionization of acids, bases, and salts:



An *electrolyte* is a solution which contains ions. An *ion* is an atom or group of atoms carrying one or more charges of electricity. It will be noted that when molecules dissociate into ions there are always formed an equal number of + and − charges. Take for instance the case of the dissociation of sulphuric acid in water.



Thus we see that while a molecule of sulphuric acid (H_2SO_4) in dissociating breaks up into three ions (two positively charged H ions and one negatively charged SO_4 ion) yet the number of positive charges on the ions so formed is equal to the number of negative charges.

442. The Electrolytic Cell. Suppose that we have a cell such as shown in Fig. 468, consisting of two similar electrodes

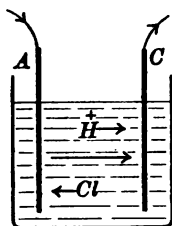


FIG. 468
Electrolytic cell

and an electrolyte. Let the electrodes be of platinum and the electrolyte be a dilute acid, for example, HCl . Now if a current be passed through this cell in a direction indicated by the arrows at A and C, the $+$ ions go *with* the current and the $-$ ions go *against* the current. The electrode toward which the $+$ ions go is called the *cathode*; the other electrode, the *anode*. It is characteristic of H ions and metallic ions to go with the current; neg-

ative ions always go against the current.

Such a cell as here described is called an *electrolytic cell*. It differs from a voltaic cell in this respect: *The voltaic cell is designed to furnish a current; the electrolytic cell is designed to electrolyze a solution.* *Electrolysis* is the process by which the ions of a solution are separated by means of a current.

443. Electrolysis of Copper Sulphate. Consider that we have an electrolytic cell, as shown in Fig. 468, in which the electrodes are of copper and the electrolyte a solution of copper sulphate, CuSO_4 . The salt dissociates as follows:

$\text{CuSO}_4 = \overset{++}{\text{Cu}} + \overset{--}{\text{SO}_4}$. The positive ions, Cu , are deposited

upon the cathode; the negative ions, SO_4 , unite with copper ions as the anode, forming CuSO_4 . Thus for every copper ion which goes out of solution at the cathode, another copper ion goes into solution at the anode, and the concentration of the Cu ions of the solution thus remain constant, so far as the cell as a whole is concerned.

If platinum instead of copper electrodes are used the following reactions will take place: At the cathode Cu ions are discharged, thus copper-plating the platinum of that electrode. At the anode SO_4 ions are discharged, and since these ions cannot react chemically with the platinum they react with the water, forming sulphuric acid, H_2SO_4 and liberating O, as in the case of the electrolysis of water.

444. The Decomposition of Water by Electrolysis. In the decomposition of water by electrolysis we use a cell of a type shown in Fig. 469. The electrodes are of platinum, which is used because this metal is not acted upon by any acid. The electrolyte is a dilute solution of sulphuric acid in water. When the current passes through such a cell, the H ions appear at the cathode, give up their positive charges, and are liberated in the form of gaseous hydrogen. Oxygen, O, is liberated at the anode.

The relation of the volume of O to the volume of H is as 1 : 2; that is, for every cubic centimeter of O liberated at the anode there are two cubic centimeters of H liberated at the cathode.

The chemical reactions which take place in the electrolysis of water containing sulphuric acid are quite complex, the nature of the reaction depending upon the e.m.f. applied. A full discussion of this subject is beyond the limits of an elementary text, it being sufficient to say that the object of

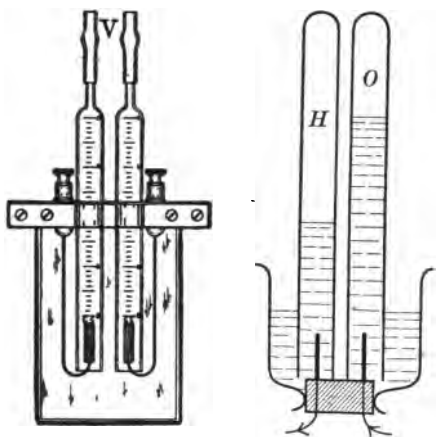
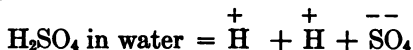


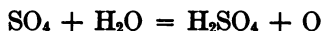
FIG. 469.—Electrolysis of water

adding sulphuric acid to the water is to increase the concentration of the ions and thus to make the solution more conducting.

Decomposition of the water occurs in this electrolytic process largely as a secondary reaction, as follows: The acid on being added to the water is dissociated into positive ions, and negative ions, thus



The H ions are discharged at the cathode forming gaseous oxygen; the SO_4 ions appear at the anode giving up their negative charges and liberating gaseous oxygen, probably after this manner.



This reaction means that the SO_4 unites with a molecule of water, H_2O , forming one molecule of H_2SO_4 and liberating one atom of O at the anode. The sulphuric acid thus formed again dissociates forming more H and SO_4 ions. And so the process continues. It will be noted that there is just as much sulphuric acid in the solution when we get through as when we started; the water molecules, however, are constantly being broken up during the process.

The electrolysis of water into hydrogen and oxygen for commercial purposes is extensively carried on at the present time.

445. The Laws of Electrolysis. The laws governing the deposition of ions by electrolysis were first announced by Faraday and are now known as Faraday's laws of electrolysis. They are two in number and may be stated as follows:

I. *The mass of a substance deposited in an electrolytic cell is proportional to the strength of the current and to the time which it flows.* This means that if a given current flowing through an electrolytic cell for 1 hour deposits 1 gram of copper, then twice as much current flowing for 2 hours will deposit 2×2 or 4 grams of copper.

II. *If the same current flows through two or more cells in series, the mass deposited at the electrodes in each cell will be proportional to the chemical equivalent of the element deposited.* The *chemical equivalent* of an element is its atomic weight divided by its valence. The relation between the atomic weight, valence, and chemical equivalents of a few typical elements is shown in the following table:

Element	Atomic weight	Valence	Chemical equivalent
H	1	1	1
O	16	2	8
Cu	63	2	31
Ag	107	1	107

Thus if there be three electrolytic cells connected in series containing in order ions as follows, H, Cu, Ag, and the same current be passed through each cell, for every gram of hydrogen liberated in one cell there will be deposited in the second cell 31 grams of copper, and in the third 107 grams of silver.

446. Practical Applications of Electrolysis. *Electroplating* is the process of coating one metal with another by electrolytic action. An electroplating tank is nothing more than a large electrolytic cell in which the electrolyte is a solution containing the ions of the metal required and in which the cathode is the object to be plated. In order that the concentration of the metallic ions in the electrolyte remain constant it is necessary to use as the anode a bar or plate of pure metal similar to that which goes out of solution at the cathode. For example, if we are silverplating we shall have to use as the anode a piece of pure silver; for nickelplating, an anode of nickel, and so on. The current used in commercial electroplating processes is usually furnished by a dynamo.

Silverplating. The silverplating of tableware, such as spoons, knives, forks, etc., Fig. 470, is a familiar illustration of the electrolysis of a silver salt. For such work a solution of

silver cyanide is used as the electrolyte, since solutions of this salt give a smooth and compact deposit. The electrolysis of silver nitrate, AgNO_3 , also furnishes a standard method of

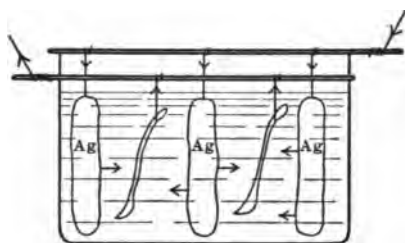


FIG. 470.—Silverplating cell

measuring a current of electricity, as will be explained later in Art. 454.

Nickel plating. The plating of bicycle and automobile parts and of household fixtures to protect articles made of brass, iron or steel is very extensively carried on. The

electrolyte is a solution of nickel ammonium sulphate.

Copper plating and electrotyping. In copper plating and electrotyping a bath of copper sulphate is employed. A piece of copper serves as the anode. The object to be plated is suspended as the cathode. In electrotyping an impression of the type after being set up is made in wax, the surface of which is coated with finely powdered graphite to render it conducting. The wax mold thus prepared is now put into the bath as the cathode, and a suitable deposit of copper made upon it.

Electrolytic refining of copper. As obtained from its ores, copper contains a number of impurities which make it objectionable for certain kinds of electrical service. To remove these impurities the electrolytic process of refining is largely employed. A large piece of impure copper is suspended as the anode in a bath of copper sulphate; a small piece of pure copper is used as the cathode. A current of proper strength is passed through the cell. The anode gradually dissolves and pure copper is deposited on the cathode.

STORAGE BATTERIES

447. Introductory. The elements of a storage battery comprise both the characteristics of a voltaic cell and those of an

electrolytic cell, in that the storage battery may be used over and over again by being alternately charged and discharged. While being charged it acts as an electrolytic cell, and on discharge it acts as a voltaic cell.

Considering its extended use in automobile lighting and starting systems, as an auxiliary in electric lighting plants, and in technical laboratory service, we have in the storage battery one of the most important appliances of modern science, millions of dollars being invested today in the manufacture and installation of battery systems of this sort. Among the many practical uses of the storage battery, in addition to those just mentioned, is its adaptation to meet the requirements of modern naval practice in the development of the submarine. The submarine can live in warfare only by stealth and so in order to steal through the water without awakening a suspicion of its presence, it must be equipped with propelling power which is practically noiseless and which leaves no visible

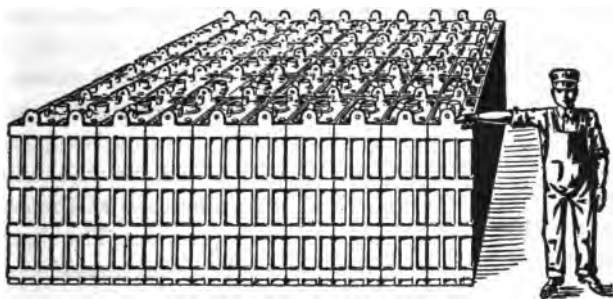


FIG. 471.—One of the storage battery units of a modern submarine, consisting of 60 giant cells

trace of its operation. The storage battery and the motor it energizes are almost ideally suited to the requirements of the submarine; for they are silent and practically heatless, leaving no trace of bubbles to betray the whereabouts of the submerged vessel.

Needless to say the submarine calls for a special type of storage battery, and it is a giant compared with the batteries seen in the common walks of life. Some idea of the size of the battery required in our large new submarines may be had from the accompanying sketch. The battery consists of two units of 60 cells each, one of these units being shown in Fig. 471. The space occupied by each unit is about 12 feet long by 12 feet wide and 50 inches high. A complete battery of two units such as described weighs between 60 and 70 tons and its capacity is approximately 300 amperes for 10 hours.

Storage batteries are of two general kinds, namely, (a) lead storage cells, and (b) the Edison or nickel-iron storage cells. The characteristics of these two types of storage cells will be discussed in detail in the articles which follow.

448. The Principle of the Storage Cell. The essential feature of the operation of a storage cell may be illustrated by means of a simple apparatus, Fig. 472, which consists of two pieces of sheet lead immersed in dilute sulphuric acid.

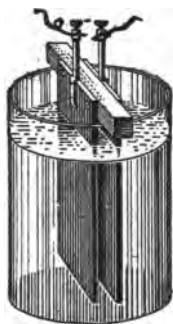


FIG. 472
Simple storage cell

The first step is to charge the cell. This is done by passing a current through the cell for a short time. During the process of being charged, the cell acts as an electrolytic cell, hydrogen being liberated at the cathode and oxygen at the anode. The hydrogen unites with any oxygen that may be associated with the cathode, thus reducing the latter to metallic lead, of a dull gray color. The oxygen, on the other hand, unites with the lead of the anode, oxidizing its surface to lead oxide, which is of a reddish brown in color. Thus when the cell is charged, one electrode consists of metallic lead, grayish in color; the other electrode is coated over with lead oxide, reddish in color. The cell is now ready to be used as a voltaic cell, in which the

red plate (lead oxide) is the positive electrode, and the gray plate (metallic lead) is the negative electrode.

The second step is to discharge the cell. Connect the electrodes to an electric bell and close the circuit. The bell will ring vigorously for some time, that is, until the cell is discharged. During discharge the current in the cell flows in the reverse direction from that of charge. This means that the hydrogen ions now go to the red oxidized plate, uniting with the oxygen to form water, thus reducing the surface of the plate to metallic lead.

In making a study of this simple storage battery the student should note several things, as follows: (a) When the cell is being charged, the charging current passes through the cell in one direction (from left to right, say), and on discharge the current furnished by the cell flows in the opposite direction; that is, the electrode which is the anode on charge becomes the cathode on discharge. (b) During charge, hydrogen gas is given off at one electrode and oxygen is liberated at the other. (c) When the cell is charged the red plate is the positive electrode and the gray plate is the negative electrode. (d) The hydrogen and oxygen liberated at the electrodes are furnished by the molecules of water (H_2O), the sulphuric acid acting as an intermediary agent as explained in the article on the electrolysis of water (Art. 444). (e) A storage battery does not, as is sometimes supposed, store up electricity; a storage battery is merely a device for storing up energy. On charging the battery the energy of an electric current is converted into potential energy by the reduction of the cathode and the oxidation of the anode.

It should be noted further that the chemical reactions which actually take place in the commercial lead storage cell are very much more complex than those which have just been described. A further account of these reactions will be given in the discussion of the lead storage battery which follows.

449. The Lead Storage Battery. A common form of the lead storage cell is shown in Fig. 473. The electrodes consist



FIG. 473
Lead storage cell

of two lead plates, with which a small quantity of the metal antimony (Sb) has been united as an alloy. The object of adding the antimony to the lead is to give stiffness and strength to the latter. The electrode which is positive on discharge is thickly coated with lead peroxide; indeed, in some types of the lead cell, lead peroxide is forced under high pressure into holes or grids which have previously been punched in the plate. To repeat what has already been started in Art. 448, the peroxide plate is reddish in color, and is the positive (+) electrode.

When a lead cell is charged, the chemical condition of the electrodes may be represented as follows: positive plate = PbO_2 (lead peroxide); negative plate = Pb (metallic lead). On discharge there is formed on both electrodes PbSO_4 (lead sulphate). The formation of lead sulphate is a necessary condition for the effective operation of a storage cell. The lead sulphate crystals are broken up chemically when the cell is recharged. Sometimes, however, this decomposition of the lead sulphate does not take place completely, in which case the cell is said to be "sulphated." This formation of permanent lead sulphate crystals in the plate proves very troublesome and seriously reduces the efficiency of the battery. Permanent sulphating is usually caused by over discharge. A lead storage battery, therefore, should never be allowed to run down completely, that is, to be completely discharged.

The resistance of the lead cell is very low. For this reason such a cell should never be short circuited. The ordinary commercial storage cell may on short circuit furnish a current

as great as 100 amperes, which if allowed to continue for any length of time would prove ruinous to the plates and connections.

The efficiency of a lead storage battery in good working order is about 80 per cent. This means that for every 100 units of energy put in, about 80 units are gotten out in useful work.

The e.m.f. of this type of cell when fully charged is high, namely 2.1 volts.

450. Precautions to Be Observed in the Use of the Lead Storage Battery. The lead storage battery is a very efficient and useful piece of apparatus; it is also a relatively expensive piece of apparatus. Its life and usefulness may be seriously impaired by careless or ignorant treatment. It is very important, therefore, to observe the following rules in handling such a battery:

1. The battery should never be short circuited.
2. The battery should not be overcharged. Overcharging causes overheating, which in turn causes the plates to bend or "buckle," thus crowding the lead peroxide out of the grids or holes, in the peroxide plate. On charging when the cells begin to "gas" freely the current should be cut off; when a storage cell begins to give off hydrogen gas freely it may in general be considered to be fully charged.
3. The battery should not be over-discharged, that is, discharged below an e.m.f. of about 1.8 volts. Over-discharge causes the plate to become permanently sulphated.
4. Only pure distilled water should be used in making up the sulphuric acid solution used as the electrolyte. Metallic impurities in the water used in a battery of this sort is fatal to the life of the cells.
5. Pure water should be added to the battery from time to time in sufficient quantities to keep the plates completely submerged. The electrolyte should just cover the top of the plates.

6. Storage batteries when not in use should be frequently charged.

451. The Edison Storage Battery. The nickel-iron storage cell, Fig. 474, was invented by Thomas Edison, hence the name "Edison storage cell." The positive electrode of this cell consists of a nickel plate, and the negative electrode consists of an iron plate, both being immersed in a solution of caustic potash (KOH) or caustic soda (NaOH). This electrolyte



FIG. 474.—Edison storage cell, showing nickel and iron electrodes

contains a solution of 21 per cent of caustic in pure distilled water. The chemical reactions of the Edison cell are not so well known as are those which occur in the lead-sulphuric acid cell. It is believed that on charge the nickel plate is oxydized to nickel oxide. On discharge the nickel oxide is reduced, and the iron electrode is oxidized to iron oxide. It is said that the Edison cell is not appreciably injured by short circuiting. One of the objects which the inventor had in mind when his cell was devised was to make it as nearly "fool proof" as possible.

The efficiency of the nickel-iron cell is somewhat below that of the lead cell. For equal current capacities, however, an Edison cell weighs only about half as much as a lead cell.

The e.m.f. of the Edison cell is about 1.2 volts.

452. Comparison of Lead with Nickel-Iron Cells. A comparison of the various factors which enter into the operation

of the lead storage cell with those of the Edison or nickel-iron storage cell is given in the following outline.

	<i>Lead Cell</i>	<i>Nickel-Iron Cell</i>
Voltage on charge.....	2.1	1.2
Energy capacity per pound..	8	12.5
Efficiency	80	60
Relative life.....	1	3
Relative cost.....	1	2.25

UNITS OF ELECTRICAL QUANTITIES

453. Introductory. The four most important units employed in measuring electrical quantities are (a) the ampere, the unit of current strength; (b) the ohm, the unit of resistance; (c) the volt, the unit of potential difference and e.m.f.; and (d) the coulomb, the unit of quantity.

Nearly all the units employed in the measurement of electrical quantities have been named in honor of some celebrated physicist or chemist. The ampere, for example, was so named in honor of Ampère, a noted French physicist; the ohm after Ohm, a German physicist. Likewise the volt and coulomb were named in honor of Volta and Coulomb, respectively, the former an Italian and the latter a Frenchman.

454. The Ampere. A standard and fundamental method of measuring a current of electricity is furnished by the electrolysis of silver nitrate, AgNO_3 . The electrolytic cell employed is called a silver voltameter, or better, a *silver coulometer*, since it measures the quantity of electricity that passes through it. One form



André Marie Ampère

of the silver coulometer is shown in Fig. 475. This is an electrolytic cell, consisting of a platinum bowl, which serves the double purpose of containing the electrolyte and acting as the

cathode. The anode is a piece of pure silver. The electrolyte employed is a solution of silver nitrate, prepared according to standard specifications. The direction of the current is indicated by the arrows.

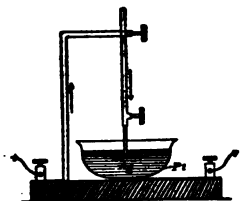


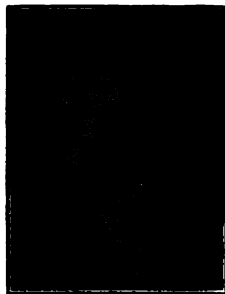
FIG. 475
Silver coulometer

Silver is deposited on the platinum cathode, the quantity thus deposited being determined by weighing the cathode (platinum bowl) both before and after the experiment. We define the unit of current strength, the ampere, in terms of the quantity of silver deposited per second.

An *ampere* is that current which will deposit 0.001118 gram of silver in one second.

455. The Ohm. Every conductor offers resistance to a current. The unit of resistance is the ohm. The *ohm* is the resistance offered to an unvarying current of electricity by a column of mercury 106.3 centimeters in length, of uniform cross section, and having a mass of 14.4521 grams, at a temperature of 0°C . The reason for selecting mercury as the standard metal in measuring the unit of resistance is (a) that it has a high resistance as compared with other metals and (b) it can be obtained in a very pure state by distillation.

Ohm discovered that for a given conductor the current strength is proportional to the e.m.f. This means that for a given conductor the resistance is independent of the strength of the current flowing through it, provided the temperature remains constant.



Georg Simon Ohm

456. The Volt. The unit of potential difference and e.m.f. is called the volt. A *volt* is the electromotive force that will

cause a current of one ampere to flow through a resistance of one ohm. The difference of potential applied to the ordinary incandescent lamp, for example, is 110 volts.

457. The Coulomb. A *coulomb* is the quantity of electricity conveyed in one second by a current of one ampere. The current that flows through a 16 candle power carbon incandescent lamp when illuminated to full candlepower is about $\frac{1}{2}$ ampere. A lamp burning for 4 hours will take $4 \times 60 \times 60 \times 0.5 = 7200$ coulombs.

MAGNETIC EFFECTS OF A CURRENT

458. The Discoveries of Oersted and Henry. It was early known that there was some very close relationship between electricity and magnetism. For example it had been observed from time to time that a discharge of lightning sometimes had the effect of magnetizing knives and other steel objects. It was believed for a long time that this magnetizing effect was due to the passage of an electric current through the objects so affected. The true relationship between electrical and magnetic phenomena, however, was not discovered until 1819, when Hans Christian Oersted, a Danish physicist, who was conducting some experiments before his class in the University of Copenhagen, by chance placed a wire carrying a current near a magnetic needle; the needle was at once deflected from the north-south direction. When the conductor was parallel with the needle and above it, the N-pole was deflected in one direction; and when the wire was placed below the needle, the N-pole was deflected in the opposite direction. This effect of a current upon a magnetic needle is known as *Oersted's discovery*.

Oersted's discovery aroused great interest among physicists, because it was at once perceived that it would not only be possible to signal at a distance by means of an electric current, but also that by means of a combination of current and magnetic systems it would be possible to transform the energy of an elec-

tric current into the energy of mechanical motion. One difficulty, however, stood in the way of the accomplishment of these highly desirable results, and that was the fact that for any considerable distance the resistance of the conductor was so great that the current flowing through it was reduced



Joseph Henry

to such a low value as to make practical results impossible. This difficulty, however, was overcome by Joseph Henry, an American scientist, who invented the electromagnet. Henry found that by winding many turns of insulated wire on an iron rod that relatively strong magnetic effects could be produced even with very weak currents.

The results growing out of the discoveries made by Oersted and Henry proved to be far reaching and of great practical importance. Indeed, every piece of electromagnetic apparatus in use today, as for example, the electric bell, the telephone, the telegraph, and all forms of dynamo electric machinery include in one form or another an application of the principles involved in these epoch making discoveries. We shall now study in detail the magnetic effects of a current, and some of the practical applications of these effects.

459. Magnetic Field about a Current. That there exists a magnetic field about a wire carrying a current may be shown in a very striking manner as follows: Pass a wire through a hole in a piece of cardboard or a glass plate upon which iron filings have been sprinkled. Now if the wire be connected to a source of e.m.f. and a rather strong current be passed through the circuit, the iron filings will arrange themselves in concentric lines about the conductor, thus showing that there is a magnetic field about the wire due to the current. The direction of the lines of induction about the wire may be deter-

mined by placing a magnetic needle upon the plate, Fig. 476. If the current through the wire be reversed the direction of the lines of induction will be reversed, as shown by the reversal of the needle. The relation between the direction of the current and the direction of the magnetic lines of induction may be illustrated by grasping the wire with the right hand with the thumb in the direction of the current, in which case the fingers will represent the direction of the lines of induction.

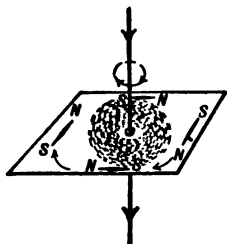


FIG. 476.—Magnetic field about a wire carrying a current

460. Effects of a Current on the Magnetic Needle. A magnetic needle always tends to set itself parallel to the direction of the lines of induction of the magnetic field in which it is placed, in such a way that the lines may be conceived of as entering the S-pole and coming out the N-pole. When a magnetic needle is placed in the earth's field it therefore takes a north-south position. Now if a wire carrying a current be brought near the needle and above it, with a current flowing in the direction indicated in Fig. 477, the needle will be acted upon by two magnetic fields, the earth's field in one direction and the magnetic field due to the wire in a direction at right angles to the earth's field. Two forces therefore act upon the needle, which takes a position representing the direction of the resultant of these forces. When the wire is above the needle, as shown in Fig. 477, the N-pole is deflected toward the observer. When the wire is placed below the needle, the current remaining in the same direction, the N-pole is deflected away from the observer.

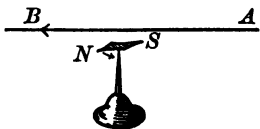


FIG. 477.—Deflection of a magnetic needle by a current

The right hand rule may conveniently be used to determine the direction and sense of the magnetic field around a conductor, and therefore the direction of deflection of the N-pole of a magnetic needle. Grasp the conductor with the



FIG. 478.—Thumb indicates direction of current; fingers, direction of magnetic field

right hand, the *thumb* pointing in the direction of the current, and the fingers will indicate the direction of the lines of magnetic induction about the wire, Fig. 478. The deflection of the N-pole therefore will always be

in the direction in which the fingers point.

According to the right hand rule, the lines of induction may be represented in another way, as illustrated in Figs. 479 and



FIG. 479
"In"
current



FIG. 480
"Out"
current

480. Suppose we are looking at the conductor "end on"; that is to say, suppose that the small circle of Fig. 479 represents a circular conductor (wire carrying a current away from the observer), and Fig. 480 represents a conductor carrying a current toward the observer. The cross is the conven-

tional symbol for an "in" current, and the dot represents an "out" current. The cross is said to symbolize the feathered end of an arrow going in, and the dot the point of the arrow coming out.

Now to consider Fig. 479, if we grasp the "in" conductor with the right hand, the thumb pointing in the direction of the current, the direction of the lines and of the magnetic field will be in a clock-wise sense, as shown; and conversely, the magnetic field of the "out" current is represented by the curved line in a counter clock-wise sense, Fig. 480.

EXERCISES. 1. Consider Fig. 477 with reference to direction of current and position of needle. Make drawings to illustrate the following cases, using the right hand rule to determine the deflection of the N-pole in each

case: (a) Current in direction BA and above needle; (b) current in direction BA and below needle.

2. Consider that the wire carrying the current, Fig. 477, be placed beside the needle, the current flowing from B to A . Determine by the right hand rule the effect on the needle.

3. Determine the direction of the current in the case of Fig. 481.

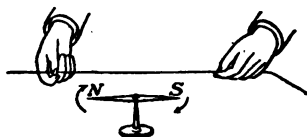


FIG. 481

461. The Solenoid. A *solenoid* consists of a coil of wire of several turns, Fig. 482, carrying a current. When a current

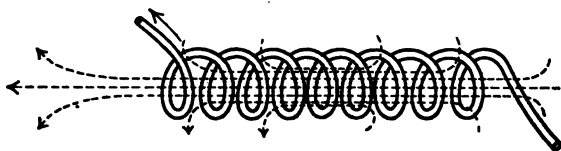


FIG. 482.—Solenoid

passes through the solenoid the coil acquires the properties of a magnet, one face or end being an N-pole and the other face or end an S-pole.

The polarity of a solenoid may be shown as follows: Pass a current through several turns of insulated wire, Fig. 483. Present one end of the solenoid to the pole of a magnetic needle; the pole is deflected in a given direction. Now present the opposite end of the solenoid to the same pole; it is deflected in the opposite direction. Thus it appears that the solenoid, like the magnet, has two poles, N and S.



FIG. 483.—Experiment to determine the polarity of a solenoid

A very simple and convenient rule for determining the polarity of a solenoid may be stated thus: Grasp the solenoid with the right hand, the *fingers* pointing in the direction of the current, and the thumb will indicate the direction of the N-pole, Fig. 484.



FIG. 484.—Right hand rule for determining the polarity of a solenoid

462. The Electromagnet. An *electromagnet* consists of a soft iron bar about which there is wound a number of turns of insulated wire, Fig. 485. The electromagnet, it will be observed, is nothing more than a solenoid having an iron core. The presence of the metal core in the coil increases enormously the strength of the magnetic field, since the iron offers a much

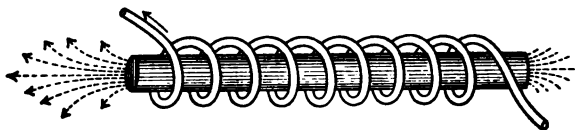


FIG. 485.—Electromagnet

easier path for the lines of induction than does the air. An electromagnet of the horseshoe type is shown in Fig. 486.

The electromagnet, as has already been stated, is used as an essential part of such electromagnetic pieces of apparatus as the electric bell, the telephone, the telegraph, the dynamo, etc. Powerful electromagnets are employed in the loading and unloading of iron, as shown in Fig. 487. When the current is turned on the electromagnet is capable of lifting a ton or more of iron. The crane to which the magnet is attached is then swung into any given position where it is desired to drop the material and the current is cut off, allowing the load *B* to fall. The object of using soft iron as the core of an electromagnet is that soft iron becomes strongly magnetized when the current is on, and quickly loses its magnetism when the

current is cut off. Tempered steel would therefore not do to use as the core of such a magnet because of its tendency to become permanently magnetized. The current is supplied to the magnet *M* through the line *L*.

463. Parallel Currents. If two conductors be suspended as shown in Fig. 488, so that the lower ends dip into mercury, and a current be allowed to flow, as indicated by the arrows, we will have the condition of parallel currents flowing in the same direction. The wires will be attracted.



FIG. 486
Electromagnet, horseshoe form

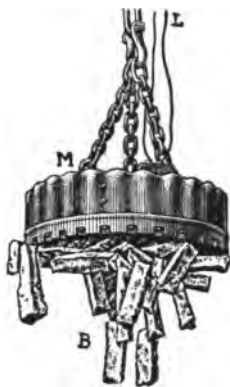


FIG. 487
Powerful electromagnet used for unloading iron bars

If now the apparatus be adjusted so that the parallel currents flow in opposite directions, Fig. 489, the conductors will repel each other.

The law of parallel currents may be stated as follows: *Parallel currents in the same direction attract; parallel currents in the opposite direction repel.*

The attraction and repulsion of parallel currents may be understood by considering the magnetic fields in the two cases. Fig. 490 shows the magnetic field about parallel currents in the same direction. Many of the lines of induction encircle both wires, and hence tend to bring them together.

In the case of magnetic fields due to parallel currents in the opposite direction, Fig. 491, the lines of induction of the two systems are crowded between the two conductors, and hence tend to force them apart.

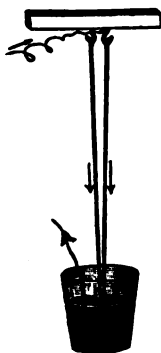


FIG. 488

Parallel currents in the same direction attract; in opposite directions, repel

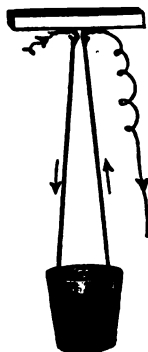


FIG. 489

464. Electrical Measuring Instruments. Electricity is today not only an agent of great interest to the student of pure science, but it is also an important commercial commodity,

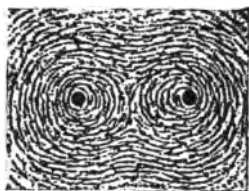


FIG. 490

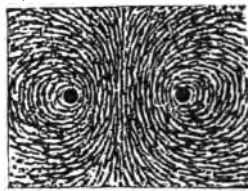


FIG. 491

Explanation of attraction and repulsion of parallel currents

and as such has to be measured. Every student who is familiar with physical laboratory practice has to use the galvanometer, the ammeter, the voltmeter, and similar pieces of apparatus; and in the shop and home also we become

familiar with the wattmeter in the measurement of power and the watthour meter in the measurement of the electric energy used for lighting and heating purposes. It is important, therefore, that the student should acquaint himself with the fundamental principles upon which these instruments work.

465. The Galvanometer. A *galvanometer* is an instrument for measuring small currents of electricity. One of the simplest forms is shown in Fig. 492. A small magnetic compass is placed in a wooden block or other non-magnetic support, around which is wrapped several turns of insulated wire. When a current flows through the conductor, the magnetic needle within the coil is deflected. This instrument is called a *tangent galvanometer* because the strength of current is proportional to the tangent of the angle of deflection. This form of galvanometer is not at present used very extensively.

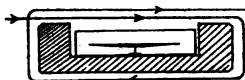


FIG. 492
Tangent galvanometer

A much more commonly used and convenient type of instrument is the *d'Arsonval galvanometer*, Fig. 493. The general principle upon which the instrument is based is shown in the accompanying outline sketch. A coil of fine wire is suspended between the poles of a horseshoe magnet in such a way that a current may enter at one point and leave at another. Now when the current flows through the coil one face becomes an N-pole, the other an S-pole, and as a result the coil swings about its axis due to the attraction of its poles for those of the permanent magnet. Attached to the coil is a pointer, or better still, a small mirror reflecting a beam of light. Thus, whenever a current flows through the instrument, its presence is indicated by the deflection of the coil. The great advantage of the d'Arsonval galvanometer over the tangent galvanometer lies not only in the fact that the former is more compact in construction and convenient in form than is the tangent galvanometer, but also that it is independent of the earth's field. The tangent

galvanometer has to be set up in such a manner that the plane of the coil lies in a north-south direction. The d'Arsonval

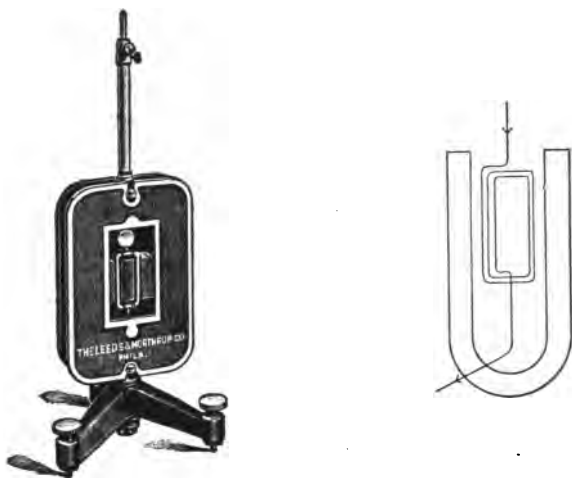
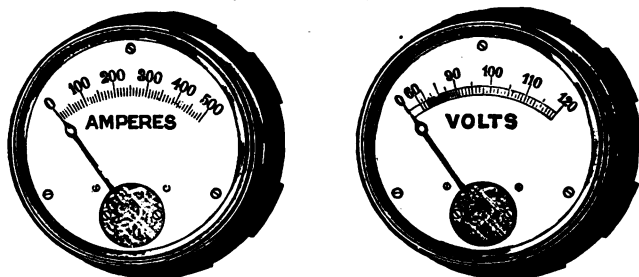


FIG. 493
D'Arsonval galvanometer



Ammeter

FIG. 494

Voltmeter

instrument, on the other hand, having a very strong magnetic field of its own due to its permanent magnet, may be set up in any position whatsoever with respect to the earth's field.

The principle of the d'Arsonval galvanometer is very extensively employed in the construction of ammeters and voltmeters, Fig. 494.

466. The Ammeter. An *ammeter* is an instrument for measuring current strength in amperes. It is really a galvanometer, usually of the d'Arsonval type, having a coil of very low resistance. A pointer and scale is provided, the latter being calibrated so as to indicate readings in amperes. An ammeter is always put in *series* with the circuit, the current of which it is designed to measure, Fig. 495.

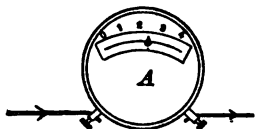


FIG. 495
Ammeter in series

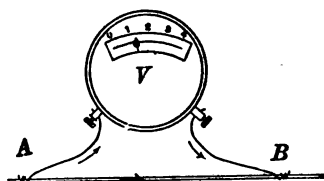


FIG. 496
Voltmeter in shunt

467. The Voltmeter. A *voltmeter* is an instrument for measuring the difference of potential in volts. Like the ammeter it is also a d'Arsonval galvanometer, but differs from the ammeter in the fact that it is provided with a coil of high resistance and also that it is calibrated to give readings in volts. A voltmeter is put in *parallel* or *shunt* with the conductor over which the potential difference is to be measured, Fig. 496, and it is for this reason that voltmeters are constructed with coils of high resistance; that is, so that the instrument will draw only a relatively small current from the main circuit.

The voltmeter shown in Fig. 496 measures the fall of potential between the points *A* and *B*.

468. The Resistance Box. In measuring resistance it is necessary to have at hand a known resistance, such as is furnished by the *resistance box* shown in Fig. 497. Such a box contains a set of *resistance coils*. A resistance coil is a coil

of wire having a definite known resistance. It is made by winding the wire in the form of a spiral, the two free ends being fastened to the metal plates *A* and *B*, *B* and *C*, which in turn are set in the resistance box. The object of winding the wire double is to prevent magnetizing effects when the current passes through the coil, and also to prevent self-induction, as

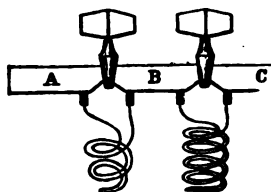


FIG. 497.—Resistance box and resistance coils

will be explained in Art. 500. The best modern resistance coils are made of manganin wire, the resistance of which is practically unaffected by ordinary changes of temperature such as occur in the laboratory. These coils are mounted in boxes with their terminals connected to the brass plates as shown. Connection from one wire of the coil to the next is made by means of a metal plug. When the plugs are all in place the resistance of the box is practically zero. When a plug is withdrawn from the box the resistance offered is equal to that of the coil beneath the particular plug withdrawn.

Resistance boxes may be bought with coils varying in resistance from 0.1 to 1000 ohms, and even greater ranges.

OHM'S LAW AND ITS APPLICATION

469. Ohm's Law. One of the most important generalizations in electricity is known as Ohm's law, which may be stated as follows: *The current in amperes is equal to the electromotive force or difference of potential in volts divided by the resistance*

in ohms. The general equation for the mathematical expression of the law is

$$I = \frac{E}{R}$$

which implies that the current in any system, such as a battery and its conducting circuit, is *directly* proportional to the electromotive force and *inversely* proportional to the resistance. This means, in the case of a battery system having a given resistance, the greater the e.m.f. the greater the current; and on the other hand, for a given e.m.f. the greater the resistance the less the current.

470. The Laws of Resistance. The resistance of a conductor depends upon the following factors: (a) The length of the conductor; (b) its cross section; (c) kind of material used; and (d) the temperature. The laws of resistance may be stated as follows:

I. *The resistance of a conductor is directly proportional to its length.* For example, if 10 feet of a given wire have a resistance of 1 ohm, 20 feet of the same wire will have a resistance of 2 ohms.

II. *The resistance of a conductor is inversely proportional to its cross sectional area.* That is, the greater the cross sectional area of a conductor, the less the resistance. Since the cross sectional area of a wire is proportional to the square of its diameter d , it is sometimes convenient to consider the resistance as inversely proportional to the square of the diameter, d^2 .

III. *The resistance of a conductor depends on the material of which it is composed.* The resistance of iron, for example, is more than six times as great as that of copper, for the same length and cross section.

IV. *The resistance of a metallic conductor increases as the temperature increases.* The hotter a wire becomes, the greater is its resistance. On the other hand, *the resistance of carbon and electrolytes decreases as the temperature increases.* The

resistance of the carbon filament of a 110 volt 16 candle power incandescent lamp is, when cold, about 440 ohms; when hot (incandescent) about 220 ohms.

471. Discussion of the Laws of Resistance. The first three laws of resistance may be expressed in the form of equations as follows:

$$R = \frac{k \times l}{a}$$

$$= \frac{k' \times l'}{d^2}$$

In the first equation given above R is the resistance in ohms, l the length of the conductor in centimeters, a the cross sectional area of the conductor in square centimeters, and k is a constant depending upon the nature of the material of which the conductor is composed. The constant k in the equation is expressed in ohms per centimeter, as given in table XXIV.

In the second equation R is again the resistance in ohms, l' the length in feet, d is the *diameter* of the wire, usually expressed in thousandths of an inch, and k' is a constant. The constant k' is usually expressed in ohms per "mil-foot," a mil-foot representing a wire 1 foot in length and 1/1000 of an inch in diameter. For example, a wire which is 3/1000 or 0.003 inch in diameter is said to have a diameter d of 3 mils.

Values of k and k' are given in the following table, in which k is given in ohms per centimeter and k' in ohms per mil-foot.

Example. 1. Find the resistance at 0°C of 50 m of aluminum wire, the radius of which is 0.5 mm. *Solution:* Referring to the Resistivity Tables, we find that the value of k in ohms per cm for aluminum is $k = 2.6 \times 10^{-6} = 0.0000026$. The length $l = 50 \text{ m} = 500 \text{ cm}$. Also, $0.5 \text{ mm} = 0.05 \text{ cm}$, and therefore $a = \pi r^2 = \pi (0.05)^2 = 25 \pi / 10,000$. Hence $R = kl/a = 0.0000026 \times 500 / (25 \pi / 10,000) = 0.52 / \pi \text{ ohm}$.

TABLE XXIV

RESISTIVITY VALUES AT 0° C

Conductor	k in Ohms per cm	k' in Ohms per mil-foot	Conductor	k in Ohms per cm	k' in Ohms per mil-foot
Aluminum.....	2.6×10^{-6}	17.5	Silver.....	1.5×10^{-6}	9.5
Copper.....	1.6×10^{-6}	10.1	Manganin 20° C	42×10^{-6}	260.0
Gold.....	2.2×10^{-6}	12.6	Mercury.....	94×10^{-6}	566.0
Iron.....	9.7×10^{-6}	58.3	Nickel.....	12×10^{-6}	75.0
German silver..	20.9×10^{-6}	125.7	Platinum.....	9×10^{-6}	54.0

Example. 2. Find the resistance at 0° C of 1 mile of copper wire, the diameter of which is 0.03 inch. *Solution:* The value of k' for copper in ohms per mil-foot is $k' = 10.1$. The length $l' = 5280$ feet. Diameter $d = 0.03 = 30/1000$ inch = 30 mils, and hence $d^2 = 900$. Then $R = k'l'/d^2 = 10.1 \times 5280/900 = 59.25$ ohms.

Example. 3. Find the resistance of the aluminum and copper conductors mentioned in Examples 1 and 2 at room temperature (20° C). *Solution:* In general an increase in temperature causes an increase in resistance. The resistance of metallic conductors increases with change of temperature from the 0° C values at the rate of 0.004 ohm per degree. The respective resistances then at 20° C are (a) $R = (0.52/\pi) + (0.52/\pi \times 0.004 \times 20) = 0.56/\pi$ ohm, and (b) $R = (59.25) + (59.25 \times 0.004 \times 20) = 63.99$ ohms.

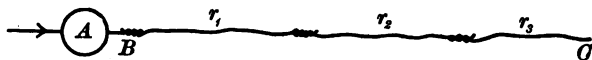


FIG. 498.—Resistance in series

472. Resistance of Conductors in Series. When conductors are joined end to end as shown in Fig. 498 they are said to be connected in *series*. The resistance of a number of con-

ductors connected in series is equal to the sum of the individual resistances; that is

$$R = r_1 + r_2 + r_3 + \dots$$

Example. Three wires having resistances of 5, 10, and 15 ohms respectively are connected in series. Find the total resistance of the combination. *Solution:* $R = 5 + 10 + 15 = 30$ ohms.

473. Resistance of Conductors in Parallel. When two or more conductors are connected as shown in Fig. 499 they are

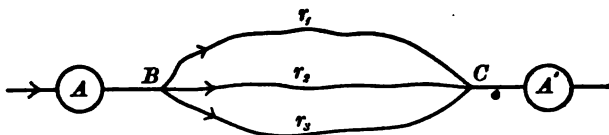


FIG. 499.—Resistance in parallel

said to be in *parallel*. It may be demonstrated that the resistance R of two or more conductors in parallel may be expressed by an equation of the following form.

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \dots$$

Example. Let r_1 , Fig. 499, be a resistance of 5 ohms, r_2 10 ohms, and r_3 15 ohms. Find the resistance of the three wires thus connected in parallel. *Solution:* $\frac{1}{R} = \frac{1}{5} + \frac{1}{10} + \frac{1}{15}$, hence $R = 2.7$ ohms.

474. Discussion of Ohm's Law. The equation for Ohm's law, $I = E/R$ is very frequently written

$$E = I R$$

This means that the fall of potential E between two points in a circuit is equal to the product of the current I times the

resistance R . The term IR is sometimes called the "IR drop" of potential. Fall in potential E is also sometimes referred to as P.D. (potential difference).

Example. The resistances shown in Fig. 498 are as follows: $r_1 = 5 \text{ ohms}$, $r_2 = 10 \text{ ohms}$, and $r_3 = 15 \text{ ohms}$. The current flowing through the system, as indicated by the ammeter A , is 2 amperes. Find (a) the IR drop over each resistance, and (b) the P.D. between B and C . **Solution:** (a) $Ir_1 = 2 \times 5 = 10 \text{ volts}$, $Ir_2 = 20 \text{ volts}$, and $Ir_3 = 30 \text{ volts}$. (b) $P.D. = E = IR = 2 \times (5 + 10 + 15) = 60 \text{ volts}$.

475. Current Strength in a Circuit. We learn from Ohm's law that, so far as direct currents are concerned, there are only two ways of increasing or decreasing the strength of a current, and that is by changing either E or R . If for example we wish to increase the current in a given system we must either increase the electromotive force E or decrease the resistance R .

It is important to note that when the value of E and R are once fixed in a *series circuit* the current strength is then the same throughout all parts of the circuit. Thus, if in a circuit containing the resistances r_1 and r_2 , Fig. 500, an ammeter be introduced successively at A , A' , and A'' , it will be found that the reading of the instrument (current in amperes) is the same at all points, that is, if the current strength at A is 3 amperes the current strength at A' and A'' is also 3 amperes.

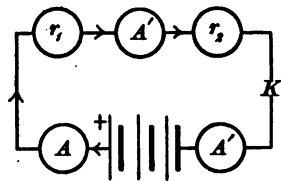


FIG. 500.—Current of same strength in all parts of circuit

In the case of a *divided circuit* consisting of two or more parts in parallel, Fig. 501, the current divides, a part flowing over each path. The current divides at A and the fractional currents unite again at A' , as is demonstrated by the fact that the reading of the ammeter at A' is equal to that at A .

In order to find the values of the currents flowing over the respective paths of a divided circuit it is necessary to know the fall of potential E from A to A' , Fig. 501, and to know also the values of the resistances r_1 , r_2 , and r_3 . The fall of potential is equal to the total resistance times the total current, that is, $E = RI$. The total current may be determined by reading

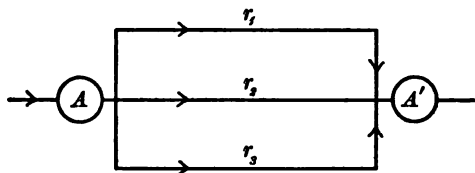


FIG. 501.—Divided circuit

ammeter A or A' ; the total resistance of the branches may be determined from the equation

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$$

Now having determined E over the divided circuit we may compute the current in the various branches thus:

$$I_1 = \frac{E}{r_1}, \quad I_2 = \frac{E}{r_2}, \quad I_3 = \frac{E}{r_3}$$

It should be noted that the total current as recorded by the ammeter is $I = I_1 + I_2 + I_3$.

476. Fall of Potential over Conductors in Parallel. Suppose that water flows from a point A through three trenches to a point B on a lower level. Now while the trenches extending from A to B may be of different lengths and the water flowing in any trench may be entirely different in quantity from that of any of the other trenches, yet we readily comprehend that the difference of pressure between the two points A and B is the same, no matter what path we consider. Suppose now that a current from a point A at high potential flows over three paths

or conductors to a point B of low potential. As in the case of the trenches, the conductors may be quite different in length and the currents of electricity flowing in each may also differ from each other, yet the fall of potential from A to B is the same, no matter which path we consider. That is, *in the case of conductors in parallel the fall of potential over each conductor is the same*, and furthermore, the fall of potential over each conductor is the same as the fall of potential from A to B obtained by multiplying the total current by the total resistance between these points.

Example. Three conductors, 4, 6, and 12 ohms respectively, connect the points A and A' , Fig. 501. A current of 6 amperes flows from A to A' , a part passing through each conductor. Find (a) the fall of potential from A to A' ; (b) the current through each wire. *Solution:* (a) *The current from A to A' = 6 amperes; the resistance from A to A' = 2 ohms. Therefore, the fall of potential from A to A' = $6 \times 2 = 12$ volts.* (b) *Now since the fall of potential from A to A' , as just found, is 12 volts, the fall of potential over any one of the three paths is also 12 volts. Hence the current in the first path will be $\frac{12}{4} = 3$ amperes; the current in the second path $\frac{12}{6} = 2$ amperes; the current in the third path $\frac{12}{12} = 1$ ampere. The total current in all three paths = $3 + 2 + 1 = 6$ amperes.*

477. Resistance by Ohm's Law. The equation $E = IR$ suggests also a method of measuring the resistance of a conductor by the application of Ohm's law. We may write $R = E/I$; in order then to determine the value of R we

must know the values of E and I . To determine these values experimentally it is necessary to use a voltmeter and an

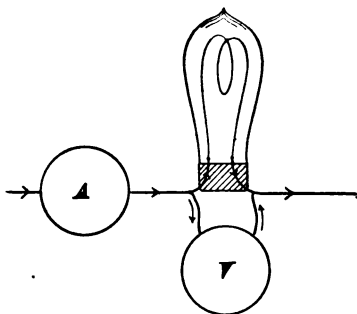


FIG. 502.—Resistance by voltmeter-ammeter method

ammeter; for this reason the method is sometimes spoken of as the *voltmeter-ammeter method* of measuring resistance.

Suppose that we desire to find the resistance of a carbon filament lamp by the voltmeter-ammeter method. An ammeter is put in series with the lamp and a voltmeter of high resistance is connected in shunt, as shown in Fig. 502. Assuming that, because of its high resistance, the voltmeter draws only a negligible current from the circuit, the current I flowing through the lamp then is practically that registered by the ammeter. The voltmeter measures the fall of potential E across the terminals of the lamp. Let us assume that the current strength as measured by the ammeter is 0.4 ampere, and that the voltage across the lamp terminals is 110 volts. The resistance of the lamp then is $R = 110/0.4 = 275$ ohms.

EXERCISES. 4. Given two conductors, the resistance of r_1 being 10 ohms and that of r_2 15 ohms. Find the resistance R of these conductors when connected (a) in series, (b) in parallel.

5. Three wires having a resistance of 2, 4 and 6 ohms respectively are connected in parallel. Find the resistance of the system.

6. The three wires of problem 5 are connected as shown in Fig. 503. Find the resistance of the system from A to C .

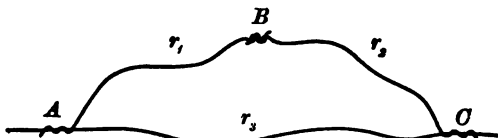


FIG. 503

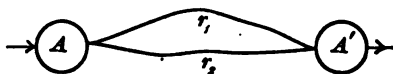


FIG. 504

7. Two conductors, r_1 having a resistance of 2 ohms and r_2 a resistance of 8 ohms, are put in parallel, Fig. 504. Ammeter A registers a current of 10 amperes. Find (a) the fall of potential over r_1 , (b) the fall of potential over r_2 .

8. What current flows (a) through r_1 (problem 7)? (b) through r_2 ? (c) through the ammeter A ?

478. Resistance by the Wheatstone Bridge Method. We have just discussed a method of determining resistance by the use of Ohm's law; that is, a method of determining R from E and I . Another very useful method is that which is known as the Wheatstone bridge method. Wheatstone's bridge, so named in honor of its inventor, Sir Charles Wheatstone, is a device for finding the value of an unknown resistance by comparing it with a known resistance. The principle of the Wheatstone bridge may be demonstrated by means of four resistance boxes connected to a cell, as shown in Fig. 505. A galvanometer is connected to the points b and d . The current from the cell divides at a , part going by the upper path of the bridge and part by the lower path. The bridge is said to be in balance when no current flows through the galvanometer. To put the bridge into balance we vary the resistances R_1 , R_2 , R_3 , and R_4 until the galvanometer shows no deflection. This means that the potential at b is equal to that at d . When this condition is realized,

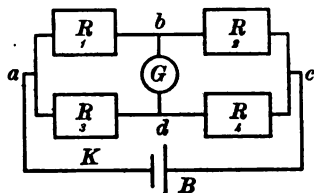


FIG. 505.—Wheatstone bridge method of measuring resistance

$$R_1 : R_2 = R_3 : R_4$$

Suppose that we have a conductor X of unknown resistance, and we wish to find its resistance by means of the Wheatstone bridge method. The conductor X is placed in the second arm of the bridge in place of R_2 , Fig. 505. The resistances R_1 , R_3 , and R_4 are then adjusted until the bridge is in balance. We may now write $R_1 : X = R_3 : R_4$, from which

$$X = \frac{R_1 R_4}{R_3}$$

In order to avoid the use of three resistance boxes, and also to facilitate the adjustment of the bridge, a device known as a *slide wire bridge* is employed, in which only one resistance box is required, a wire, ab , Fig. 506, taking the place of R_2 and R_4 . The unknown resistance is put in at X and the sliding contact m is placed near the middle of the wire. The resistance in R_1 is adjusted so as to get as nearly as possible a balance. The sliding contact m is then moved to the right or left until the galvanometer G shows no deflection. The bridge is now in balance. Since the

resistance of each section of the wire is proportional to the respective lengths a and b , we have

$$R_1 : X = a : b$$

The slide wire bridge is extensively used in laboratory electrical measurements.

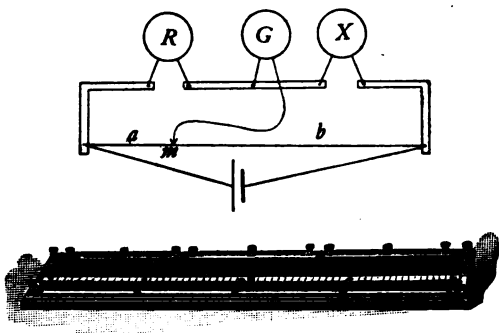


FIG. 506.—Slide wire bridge

479. Methods of Joining Cells. Ohm's law may be applied to determine the best method of joining the cells of a battery. The current furnished by a battery of one or more cells is determined by the electromotive force E and by the total resistance of the system. The resistance of a battery circuit is made up of two parts, that of the conductors connected to the poles, called the external resistance R , and that of the battery itself, called the internal resistance r . The internal resistance of a battery depends upon the nature of the materials of which it is made, including electrodes and electrolyte, and upon the size of the plates. It is important to keep in mind, in this connection, the fact that the e.m.f. of a cell is independent of the size of the plates. The resistance of a cell, however, diminishes as the size of the electrodes (plates) is increased; in other words, the larger the electrodes the less the internal resistance r .

The cells of a battery may in general be joined in two ways: (a) in series, and (b) in parallel.

480. Cells in Series. When cells are connected in series the connecting wires join positive pole to negative pole, as shown in Fig. 507. A diagrammatic representation of cells in series is given in Fig. 508.

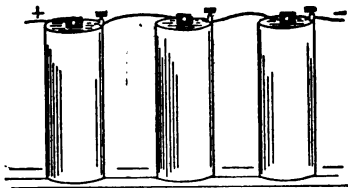


FIG. 507

Cells joined in series

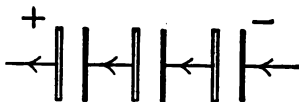


Fig. 508

According to Ohm's law the current furnished by a *single cell* is

$$I = \frac{E}{R+r}$$

in which R is the resistance of the external circuit and r is the internal resistance of the cell.

When a number of cells (n) are joined in series the equation becomes for *n cells in series*

$$I = \frac{nE}{R+nr}$$

Thus the effect of joining n cells in series is to be made the total electromotive force and internal resistance respectively n times that of a single cell.

481. Cells in Parallel. When cells are connected in *parallel*, all the positive electrodes are joined together, and likewise all the negative electrodes, Fig. 509. The diagrammatic representation of cells in parallel is shown in Fig. 510. The effect of connecting a group of similar cells constituting a battery in parallel is equivalent to producing a single cell, having an e.m.f. equal to one of the original cells, the plates of which are n times as large as those of any one of the original cells, and the

internal resistance, therefore, is r/n . Since the electromotive force of a battery is independent of the size of the plates, the e.m.f. of n cells joined in parallel is equal to that of any single

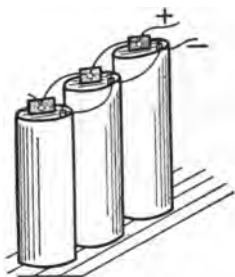


FIG. 509

Cells joined in parallel

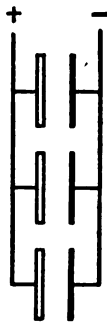


FIG. 510

cell. By Ohm's law, therefore, we may write for n cells in parallel

$$I = \frac{E}{R + r/n}$$

482. The Advantage of Cells in Series and in Parallel. The relation of the current I to the external resistance R for cells connected in series and in parallel may be demonstrated most satisfactorily by means of examples. Given three like cells, the electromotive force E of each 1 volt, the internal resistance r of each 3 ohms.

Example 1. Find the current furnished through an external resistance R of 21 ohms (a) for a single cell; (b) when the cells are joined in series; and (c) in parallel. *Solution:*

(a) *Single cell,* $I = E/(R+r) = 1/(21+3) = 0.041$

(b) *Series,* $I = nE/(R+nr) = 3/(21+9) = 0.1$

(c) *Parallel,* $I = E/(R+r/n) = 1/(21+1) = 0.045$

It thus appears that, with the external resistance R greater than the internal resistance r , as in this case, the series arrangement

gives a current nearly three times as great as that furnished by a single cell; while on the other hand, the parallel method of joining gives a current only a trifle in excess of that produced by a single cell.

When, on the other hand, the external resistance R is less than the internal resistance r of a single cell of the battery, the parallel method of joining is to be preferred, as is illustrated by the following example.

Example 2. With the same cells as employed in Example 1 find the current furnished through a resistance R of 0.1 ohm (a) for a single cell; (b) when the cells are connected in series; (c) in parallel. *Solution:*

$$(a) \text{ Single cell, } I = E/(R+r) = 1/3.1 = 0.32$$

$$(b) \text{ Series, } I = nE/(R+nr) = 3/9.1 = 0.33$$

$$(c) \text{ Parallel, } I = E/(R+r/n) = 1/1.1 = 0.91$$

Conclusions: (a) When the external resistance R is greater than the internal resistance of a single cell, the series plan of connecting the cells of a battery gives the greater current. (b) When R is less than r , the parallel method is the more desirable. (c) Since the external resistance R is nearly always greater than the internal resistance r , cells are in general connected in series. The parallel method is sometimes employed, however, in charging and discharging storage batteries.

HEAT AND POWER EXPENDED BY A CURRENT

483. The Electric Current as a Heating Agent. Whenever a current of electricity flows through a conductor heat is developed. The case that is most familiar is that of the heating of the filament of an incandescent lamp. Other illustrations of the heating effect of a current are exemplified in the use of the electric flatiron, Fig. 511, the electric soldering iron, and similar appliances. Electric currents are also used in some places for cooking, Fig. 512, and occasionally for the heating of rooms.

The diagram shown in Fig. 511, illustrates the arrangement of the heating elements of the electric flatiron. These heating elements (conductors) are usually built up by winding a thin

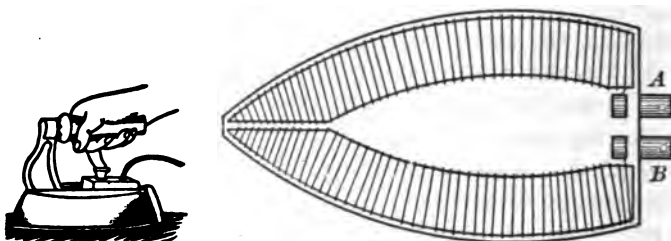


FIG. 511.—Electric flatiron and heating elements

ribbon of "nichrome" (nickel-chromium) upon an insulating support made of asbestos or mica. In the use of the electric current as a heating agent in the cook stove or range great



FIG. 512.—Electric cook stove

care should be exercised to keep the heating elements free from moisture or other conducting media to prevent the short circuiting of the heating elements.

Electric heating recommends itself more on account of its convenience than on account of its cheapness. In the case of an electric flatiron, for example, the heat may be turned on or off by simply opening or closing a switch. In this connection it should be remembered that the

utmost care should be exercised to see that the circuit is opened when the instrument is not in use, as serious fires have been

caused by over heated flatirons and other like pieces of domestic electrical heating appliances. When one is through with a flatiron the best way to break the circuit is to detach the connecting plug at the contacts *A* and *B* (Fig. 511); one is then sure that the current is broken and that no damage will result.

The power used by the ordinary electric flatiron is equivalent to that consumed by about 20 25-watt incandescent lamps.

484. The Laws of Heat Development by a Current. By means of a simple calorimeter, Fig. 513, in which a current of electricity was passed through a wire immersed in a nonconducting fluid, Joule was able to determine the relation of the number of heat units *H*, developed by the current *I* flowing through a resistance *R* in the time *t*. This relation is expressed in the following laws:

I. *The heat is proportional to the time which the current flows.*

II. *The heat is proportional to the resistance of the conductor.*

III. *The heat is proportional to the square of the current.* That is, if a current of 1 ampere develops 1 unit of heat per second, then a current of 10 amperes will develop $10^2=100$ units of heat per second.

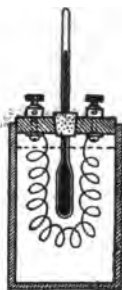


FIG. 513
Electric
calorimeter

These laws may be expressed by the equation

$$H = I^2 \times R \times t \times 0.24 = \text{calories}$$

in which *H* is the heat in calories, *I* the current in amperes, *R* the resistance in ohms, and *t* the time in seconds. The factor 0.24 which appears in this equation was determined experimentally; it is the number by which it is necessary to multiply in order to express *H* in calories.

It is sometimes desirable to write the foregoing equation in a little different way so as to express the heat value in terms of

volts times amperes. Since $I^2R = IR \times I$, and also since $IR = E$, we may write our general equation as follows:

$$H = E \times I \times t \times 0.24 = \text{calories}$$

where H , as before, is expressed in calories, E is the difference in potential over the conductor, measured in volts; I is the current in amperes and t the time in seconds.

Example 1. A current of 2 amperes flows through a conductor having a resistance of 5 ohms for 10 minutes. Find the heat developed in calories. *Solution:* $H = I^2Rt \times 0.24 = 4 \times 5 \times 10 \times 60 \times 0.24 = 2880 \text{ calories}$.

Example 2. An electric flatiron connected to a 110 volt circuit draws a current of 4 amperes. Find the heat in calories developed in the flatiron in half an hour. *Solution:* $H = EIt \times 0.24 = 110 \times 4 \times 30 \times 60 \times 0.24 = 190,080 \text{ calories}$.

EXERCISES. 9. A current of 3 amperes flows through an iron wire conductor for 2 hours. The length of the wire is 4 m; its cross sectional area, 0.03 cm^2 ; the value of k for the given temperature, 0.0000174. Find the heat in calories developed in the conductor.

10. An electric toaster which takes 5 amperes at 110 volts toasts a slice of bread in 2 minutes. Find the heat developed in calories.

485. Electric Fuses. In the principle involved in the use of the safety fuse, advantage is taken of the heating effect of a current. The *electric fuse* is a device for automatically breaking the circuit in case, for a given system, the current becomes dangerously high. Fuse wires are made of some high resistance material which has a low melting point. Suppose, for example, that a fuse be placed in a circuit containing a piece of apparatus, the maximum carrying capacity of which is 2.5 amperes, but which is designed to be operated, under ordinary conditions, with a current of 2 amperes or less. If now for any reason the current should tend to rise above the carrying capacity of the instrument the fuse wire would melt at 2 amperes and thus save the apparatus from burning out.

Since the melting or "blowing" of a fuse wire is always accompanied by the formation of an electric arc which is likely to set fire to nearby inflammable material, fuses are usually enclosed in fireproof receptacles called fuse plugs, Fig. 514.



FIG. 514

Electric fuses

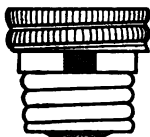


FIG. 515

In dwelling houses a capsule like fuse plug is frequently employed, Fig. 515, which is so designed as to screw into place in the fuse box. The capacity of these house fuses is usually about 5 amperes; that is, they are designed to melt when the current much exceeds this value.

486. Electric Power. The power expended by an electric current (electrical energy per second) is expressed in watts, or more frequently in kilowatts. The *watt* as defined electrically is volts times amperes, that is,

$$\text{watts} = \text{volts} \times \text{amperes} = EI$$

In this connection it should be noted that a watt as defined electrically does not differ in magnitude from the watt as defined mechanically (Art. 71). That is to say, 1 volt $\times$ 1 ampere = 1 watt = 10,000,000 ergs per second = 1 joule per second. One *kilowatt* = 1000 *watts*. It should also be borne in mind that whenever we speak of a watt or a kilowatt, these terms refer to units of *power*; that is, they represent a given expenditure of energy *per second*. Thus, a 40-watt lamp is a lamp that consumes energy at the rate of 40 watts, which is equivalent to a consumption of energy at the rate of $40 \times 10,000,000 = 400,000,000$ ergs per second.

487. Total Energy Expended by a Current. Since the watt and kilowatt represent the expenditure of energy per second, it follows that if we desire to compute the *total energy* expended by a current in a given time (one hour, say), we must multiply the power (watts or kilowatts) by the time which the current flows. The units thus employed to express the total energy expended are the watthour and the kilowatthour. A *watthour* represents an expenditure of energy at the rate of one watt for one hour; and likewise a *kilowatthour* is an expenditure of energy at the rate of one kilowatt for one hour. Also, since one watt is equivalent to 10^7 ergs per second, and one hour is $60 \times 60 = 3600$ seconds, it follows that one watthour represents a total expenditure of energy which may be expressed as follows:

$$\text{one watthour} = 10,000,000 \times 60 \times 60 \text{ ergs} = 36 \times 10^9 \text{ ergs}$$

Example. A current of $\frac{1}{2}$ ampere under a pressure of 110 volts flows through an incandescent lamp for 5 hours. (a) Find the power expended in watts. (b) Find the energy expended in watthours. (c) Find the energy expended in kilowatthours. (d) Find the total energy expended in ergs.

Solution: (a) $\text{Watts} = EI$; hence $110 \times \frac{1}{2} = 55 \text{ watts}$. (b) $\text{Watthours} = \text{watts} \times \text{time in hours} = 55 \times 5 = 275 \text{ watthours}$. (c) 1 kilowatt = 1000 watts; therefore 275 watthours = 0.275 kilowatthour. (d) 1 watt represents the expenditure of energy of 10,000,000 ergs per second; hence the total energy expended in ergs = $55 \times 5 \times 60 \times 60 \times 10,000,000 = 99 \times 10^{11} \text{ ergs}$.

EXERCISES. 11. Given a tungsten lamp, across the terminals of which there is impressed an e.m.f. for 110 volts, giving rise to a current of 0.25 ampere, which flows for 4 hours. Find the heat expended in calories.

12. Find the power expended by the lamp in (a) watts, (b) kilowatts.

13. Find the total electrical energy expended during the 4 hours, in (a) watt hours, (b) kilowatt-hours.

14. Find the total energy expended by the lamp (problem 13) in (a) ergs, (b) joules (Art. 486).

15. What will be the cost of running this lamp for 4 hours at the rate at which electrical energy is sold in your town?

488. The Watthour Meter. A *watthour meter* is an instrument for summing up the energy delivered to an electric circuit. By means of a system of dials, similar to those on a gas meter, the total electrical energy delivered to the consumer in a given time is expressed in kilowatthours. The consumer thus pays for the electricity at so much per kilowatthour.

The mechanism of a watt-hour meter, Fig. 516, is essentially that of a small electric motor, the armature of which revolves at a speed which is proportional to the watts used. The rotating part (armature) is geared to a set of recording dials which register the kilowatthours in thousands, hundreds, tens, and units respectively, as shown in Fig. 517.



FIG. 516.—Watthour meter

489. The Incandescent Lamp. At the present time the most important commercial application of the heating effect

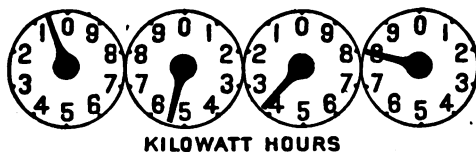


FIG. 517.—Recording dials of a watthour meter

of a current is in the production of light, as in the case of incandescent and arc lighting systems. In the incandescent lamp a filament of some nonfusible substance is enclosed within a glass bulb, from which the air is exhausted. The

object of removing the air from the bulb is to prevent the burning out of the filament due to the presence of oxygen.

The essential parts of an incandescent lamp are shown in Fig. 518. The current is conducted to and from the lamp by means of copper wires *cc*. It is conducted through the glass by means of short wires *pp* composed of a substance which has practically the same coefficient of expansion as glass, the object being to prevent the cracking of the glass due to changes in temperature. Platinum has been extensively used for this purpose. The short wires *pp* are much exaggerated in the figure for the purpose of illustration. The filament consists of some non-fusible substance which on being heated to incandescence furnishes the light.

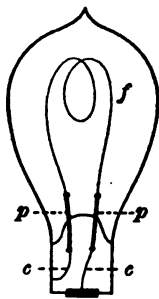


FIG. 518
Diagram of an
incandescent
lamp

The first commercial incandescent lamps brought out contained carbon filaments; these are known as carbon lamps. The filament of the modern incandescent lamp is made of wire drawn from the metal tungsten; these lamps are known as tungsten lamps. The term "mazda" is a trade name given to certain types of the tungsten lamp.

490. Comparison of Incandescent Lamps. Carbon lamp. The filament of a carbon incandescent lamp consists of an especially prepared thread of carbon. For a given expenditure of electrical energy the candle power is low as compared with the more modern types of electric lamps. Carbon incandescent lamps have been almost entirely driven out of use for commercial lighting purposes by the more efficient tungsten lamps. Carbon lamps are employed to a limited extent in physical laboratories to serve as convenient resistance



FIG. 519
Carbon lamp rheostat

units in lamp rheostats, Fig. 519, and also to serve as standards of illumination (Art. 329).

Tungsten lamp. The development of this type of incandescent lamp, Fig. 520, was made possible by the discovery that the metal tungsten could be drawn into fine wire, and that this wire could be heated to bright incandescence without reaching the melting point.

A tungsten lamp is about three times as efficient as a carbon lamp. For example, a 16 candlepower carbon lamp requires an expenditure of electrical energy of about 55 watts, that is, $55/16 = 3.44$ watts per candlepower; the tungsten lamp, on the other hand, requires only about 1.25 watts per candlepower.



FIG. 520
Tungsten incandescent
lamp

Nitrogen lamp. By first exhausting the bulb of an incandescent lamp and then filling it with nitrogen gas, a non-supporter of combustion, a very efficient type of the tungsten lamp has been produced. In this lamp the tungsten filament is wound into a fine spiral to minimize heat radiation. The presence of the nitrogen in the lamp tends to retard the evaporation of the filament, thus making it possible to raise the temperature of the tungsten much higher than is permissible in a vacuum. This increase of temperature gives rise to a corresponding increase in illumination.

The efficiency of the larger sizes of the nitrogen filled tungsten lamps is more than five times that of the carbon lamps, the expenditure of energy being only about 0.6 watt per candlepower.

491. Incandescent Lamp Circuits. Incandescent lamps are in general connected in parallel between the mains which lead from the dynamo (direct or alternating) or from the low voltage side of a transformer (Art. 512). The method of

connecting incandescent lamps in parallel is shown in Fig. 521. Each lamp of a circuit may be turned on or off by means of a key in the socket; all the lamps of the circuit may be turned

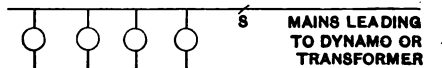


FIG. 521.—Incandescent lamp circuit

on or off by means of a switch *S*. The resistance of the incandescent lamp is comparatively high, that of the 40 watt tungsten lamp being, when hot, about 250 ohms. When the lamps are connected in parallel the resistance of the system, however, is very materially reduced. Also, when the lamps are in parallel one or more may be turned off without seriously disturbing the rest of the circuit.

492. The Arc Lamp. The essential features of an arc lamp consist of two sticks of carbon, the ends of which touch. When



FIG. 522.—Electric arc

a current is passed through the line the carbon points are drawn apart for a short distance, usually by means of an electromagnet connected with the lamp. The current passes across the air gap there formed and heats the tips of the carbons to incandescence. One carbon, the upper one in Fig. 522, is called the positive carbon and the other the negative. In the space between the carbons there is formed a volatilized carbon arc which serves as a conductor from one point to the other; it is called the *electric arc* because of its curved shape. The positive carbon is very much the hotter of the two and furnishes the greater part of the light. In the

positive carbon there is a depression which is called the *crater*. The temperature of this crater when the lamp is heated is

about 3800°C , which is probably the highest temperature attainable by present methods.

In operating arc lighting systems the lamps are put in series, as indicated by the diagram of Fig. 523. If one lamp should go out provision is made that the current be conducted around it by an automatic device, thus preventing all the lamps on the circuit being put out of commission. The ordinary arc lamp requires a difference of potential between the carbons of about 50 volts; the current required to operate the lamp is from 5 to 10 amperes.

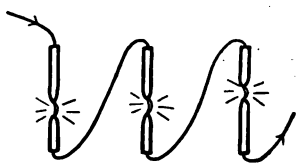


FIG. 523
Electric arc lamps in series

493. Kinds of Arc Lamps. *Open arc.* In the open arc the carbons burn in the air. In this case the positive carbon wastes away about twice as fast as the negative, and both are consumed much more rapidly than if they were enclosed in some noncombustible medium. To add to the length of life of the carbon, the so-called enclosed arc lamp is employed.

Enclosed arc. In the enclosed arc lamps, Fig. 524, the carbons are placed within a small globe which is nearly air tight. After the lamp has been burning for a short time all the oxygen within the globe is consumed, and the carbons then burn in an oxygen free gas, mainly carbon dioxide. In this form of arc lamp the consumption of the carbon is very materially decreased, but the luminous efficiency of the lamp is also decreased.



FIG. 524
Enclosed arc

Flaming arc. In the ordinary arc lamp described above most of the light comes from the crater of the positive carbon, very little being given out by the arc. In lamps of the flaming arc type the carbons contain a mixture of lime, magnesia, and other substances,

which give to the arc its brilliant flaming character. In such lamps the arc itself is the chief source of light.

The flaming arc as an illuminating agent is very efficient, its consumption of electrical energy being only about 0.3 watt per candlepower.

494. The Mercury Vapor Lamp. The Cooper-Hewitt *mercury vapor lamp* consists of an exhausted glass tube, *AB*, Fig. 525, having at the elevated end *A* the positive electrode

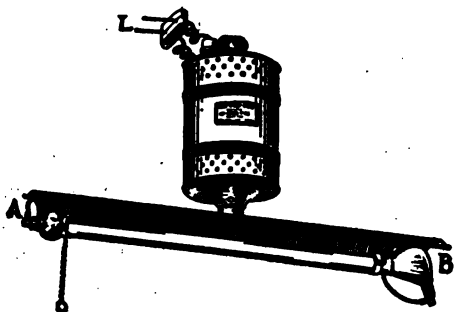


FIG. 525.—Mercury vapor lamp

which is made of iron, and at the end *B* the negative electrode, consisting of some mercury which is contained in a receptacle or bowl, *B*. In this lamp the incandescent medium is a column of mercury vapor, extending within the tube from *B* to *A*. Under a sufficiently high difference of potential between the electrodes a mercury vapor arc is formed. This arc emits a brilliant and characteristic greenish light, which is almost entirely wanting in red rays.

Mercury vapor lamps are extensively used in photography because of the strength of the actinic rays (Art. 373), and also for illuminating purposes in certain manufacturing processes.

495. Electric Lamp Efficiency. The *efficiency of an electric lamp* is measured by the number of watts consumed per candlepower. The student should note that the term "efficiency"

is used here in a peculiar sense, since the higher the wattage per candlepower the lower the lamp efficiency. For example, the carbon filament incandescent lamp requires about 3.5 watts per candlepower while the tungsten lamp requires only about 1.25 watts per candlepower. We say, therefore, that the lamp efficiency of the tungsten lamp is about three times ($3.5/1.25 = 2.8$) that of the carbon lamp.

The lamp efficiency of various types of electric lamps is given in the following table in approximate watts per candlepower.

TABLE XXV
ELECTRIC LAMP EFFICIENCY

<i>Incandescent Lamps</i>	<i>Watts per cp.</i>	<i>Arc Lamps</i>	<i>Watts per cp.</i>
Carbon Filament.....	3.5	Carbon Arc.....	0.8
Tungsten Filament....	1.25	Mercury Arc.....	0.6
Nitrogen-Tungsten....	0.6	Flaming Arc.....	0.3

496. Causes of High Bills for Electricity. When the monthly electricity bills seem unusually high the watthour meter is the first thing to be suspected; in reality, however, it is usually the last thing to blame. Some of the reasons for abnormally high bills for electric energy are the following:

1. Cloudy or rainy weather, requiring use of light in day-light hours.
2. Additional lamps may have been installed, or small lamps may have been replaced by larger ones.
3. Old dim lamps may be in use and in order to get sufficient illumination more of them must be lighted than would be necessary if lamps in good condition were used. A dim lamp takes practically as much current as a new one, and is a very wasteful thing to use. In this connection it may be well to

state that the tungsten lamp has been improved in quality and reduced in price to such an extent that no customer can afford to use carbon lamps, even if he were paid a bonus on each lamp for so doing.

4. Lamps are sometimes left burning for days in attics, closets, and other out of the way places.

5. Electric laundry irons, toasters, and other heating devices may have been placed in service, or some motor driven device such as the electric washing machine may have been installed. It is often erroneously believed that because such devices can be operated from a lamp socket they require no more power than a lamp. The extent of this error may be realized when it is borne in mind that a 6-pound laundry iron takes as much power as 20 tungsten lamps of about 20 candlepower each.

6. Defective wiring may allow current to flow when no lights or other devices are in use.

7. When electric elevators or electrically driven machinery is used and not properly oiled and cared for, excessive friction may result, with a corresponding waste of power and increase in the bill for electric current.

8. An error may be made by the company's meter reader, so that the bill rendered is too high or too low. If it is too high, the bill for the following month will be low by the same amount, if the meter is then read correctly, and consequently the consumer will not lose anything in the long run.

REVIEW EXERCISES

1. Make a sketch of a voltaic cell, and in connection with this sketch point out and define (a) positive electrode, (b) negative electrode, (c) electrolyte, (d) external circuit, (e) internal circuit.

2. Explain how we may determine which electrode of a cell is positively charged.

3. Given two cells, one having electrodes of copper and zinc, and the other electrodes of copper and carbon. Which element is the positive electrode (a) in the first cell? (b) in the second cell?

4. What is electromotive force? To what is it sometimes likened? Is it a force? In what units is it measured?

5. Define local action and explain how it may be remedied.

6. Define polarization. How does polarization affect the e.m.f. of a cell? How may polarization be remedied?

7. Name the factors which determine the e.m.f. of a cell. Does the e.m.f. depend upon the size of the plates? What advantage has a large cell over a small one?

8. Name the electrodes and the electrolytes used in each case of the following cells: (a) gravity, (b) Leclanché, (c) dry cell. Give the e.m.f. in each case. What cell would you use on open circuit work, and why?

9. What is electrolytic dissociation? What is an ion? Write equations to illustrate the dissociation of (a) hydrochloric acid, (b) sulphuric acid, (c) copper sulphate.

10. Make a sketch of an electrolytic cell the electrolyte of which is a solution of HCl in water. Indicate (a) the direction of the current through the cell, (b) the direction in which the $+$ ion moves; (c) the $-$ ion.

11. Explain briefly the decomposition of water by electrolysis. What gas appears at (a) the anode? (b) the cathode? What are the relative volumes of hydrogen and oxygen?

12. State Faraday's laws of electrolysis.

13. A current of one ampere will deposit by electrolysis 0.001118 gram of silver in one second. What current will be required to deposit 100 grams of silver in 2 hours?

14. A current of one ampere flows through two electrolytic cells in series, one containing silver nitrate (AgNO_3) and the other copper sulphate (CuSO_4). (a) How much silver will be deposited in 1 hour? (b) How much copper?

15. In electroplating what metal is used as the anode?

16. In charging a storage battery, do we put current into it or through it? What is stored up in a charged battery?

17. The lead storage cell. On discharge, what is the anode? the cathode? What is the electrolyte? The e.m.f. when charged? Efficiency?

18. State precautions to be observed in use of the lead storage battery.

19. Describe briefly the Edison storage cell. Compare the nickel-iron cell with the lead cell.

20. Make drawing to illustrate the silver coulometer, and explain its use in determining current strength.

21. Define: (a) ampere, (b) ohm, (c) volt, (d) coulomb.

22. Discuss the discoveries made by Oersted and Henry.

23. A wire which is stretched in a north-south direction carries a current. (a) It is desired to find the direction of the current, and to this end a magnetic needle is placed below the wire. The N-pole of the needle is deflected to the east. Determine by the right-hand rule the direction of the current in the wire. (b) On another occasion the needle was placed above the wire, the N-pole being again deflected to the east. Find the direction of the current.

24. Wrap a string around a lead pencil after the manner of the solenoid. Consider the current to flow in a given direction in the string, and determine by the right-hand rule the polarity of the point of the pencil.

25. Why is soft iron instead of steel used as the core of electromagnets?

26. Explain the operation of the d'Arsonval galvanometer, and tell what advantages it possesses over the tangent galvanometer.

27. (a) How is an ammeter connected in a circuit? (b) a voltmeter? (c) Why should the resistance of an ammeter be low and that of a voltmeter be high?

28. State Ohm's law; write the law in the form of an equation.

29. (a) On what four factors does the resistance of a conductor depend? (b) State the laws of resistance in the form of an equation.

30. The resistance of a given piece of wire of length l and diameter d is 4 ohms. How will the resistance be affected (a) if the length be doubled, d remaining the same? (b) if both length and diameter be doubled?

31. Find the resistance of 10 m. of German silver wire, the diameter of which is 0.4 mm and the value of k 0.000021 ohm per cm.

32. Find the resistance of 10 ft. of No. 30 iron wire at 20°C . To find k' for iron at 0°C , see Table XXIV; to find the diameter of No. 30 wire in mils, see Table I, page 14.

33. A conductor consists of three wires connected in series, the resistance of the wires being 10, 20 and 30 ohms respectively. What is the resistance of the conductor?

34. A current of 2 amperes flows through the conductor of problem 33. Find (a) the fall of potential ($E = RI$) over each of the three wires; (b) the fall of potential over the entire conductor.

35. Two wires of 20 and 30 ohms resistance are connected in parallel between the points A and B . Find the resistance of the two wires thus connected.

36. The total current flowing from A to B (problem 35) is 2 amperes. Find (a) the fall of potential from A to B ; (b) the fall of potential over each wire; (c) the current in each wire.

37. The current for an open arc lamp is 10 amperes. The potential at its terminals is 50 volts. (a) What is its resistance? (b) What resistance must be put in series with the lamp if used on a 110-volt circuit?

38. A current flows through the two wires of problem 35, between the points *A* and *B*. The portion of the current flowing through the first wire (20 ohms) is 3 amperes; that through the second, 2 amperes. What is the fall of potential over (a) the first wire? (b) the second wire?

39. A current of 11 amperes flows from *A* to *B* over a divided circuit consisting of three wires in parallel. The resistance of the wires is 10, 20, and 30 ohms respectively. Find (a) the total resistance between *A* and *B*; (b) the fall of potential between *A* and *B*; (c) the current in each wire.

40. It is desired to find the resistance of a given conductor, *AB*, by Ohm's law. A current is passed through the conductor. An ammeter placed in the circuit reads 2 amperes. A voltmeter connected to the terminals *A* and *B* indicates a fall of potential of 3 volts. Find the resistance between *A* and *B*.

41. Five gravity cells, each having an e.m.f. of 1 volt and an internal resistance of 5 ohms, are joined in series. A wire having a resistance of 25 ohms is connected to the terminals of the battery. Find (a) the resistance of the entire circuit; (b) the current flowing in the wire.

42. Suppose that the 5 cells of problem 39 are connected in parallel. What current will flow through the wire?

43. The e.m.f. of a battery is equal to the fall of potential around the entire circuit. A wire having a resistance of 2 ohms is connected to the terminals of a cell having an internal resistance of 1 ohm. The current flowing through the circuit is 0.5 ampere. Find (a) the fall of potential over the external circuit; (b) over the internal circuit; (c) around the entire circuit. What is the e.m.f. of the cell?

44. Three dry cells, each having an e.m.f. of 1.5 volts and an internal resistance of 1 ohm, are connected in series to a conductor having a resistance of 7 ohms. Find (a) the resistance of the entire circuit; (b) the current in the conductor; (c) the fall of potential over the conductor; (d) the fall of potential over the internal circuit; (e) the total fall of potential around the entire circuit. How does this total fall of potential compare with the e.m.f. of the battery?

45. Given three like cells, e.m.f. of each 1 volt, internal resistance of each 3 ohms. Which is the better method of joining these cells (series or parallel), the external resistance being 3 ohms?

46. Define: (a) watt, (b) kilowatt, (c) watthour, (d) kilowatthour.

47. A current of 2 amperes flows through a conductor of resistance 40 ohms for 1.5 hours. (a) Find the power expended in watts; kilowatts. (b) Find the total energy expended in watthours; kilowatthours. (c) Find the total energy in ergs; joules.

48. The ordinary electric flatiron requires about 600 watts. An iron of this sort is operated on a 110 volt circuit. (a) The power used by the iron would operate how many 25-watt lamps? (b) What current does the iron take? (c) How many calories of heat are developed in one hour?

49. Compute the cost of operating the flatiron (problem 48) for one hour at the rate at which electrical energy is sold in your town.

50. A street car uses 100 amperes at 600 volts pressure. What power is delivered to it? Express also in kilowatts and horsepower.

51. How many B.t.u. are given off in an electric oven that takes 10 amperes at 110 volts for 1 hour?

52. An electric heater supplies heat at the rate of 700 B.t.u. an hour. How much power does it require?

53. Read the electric meter dials shown in Fig. 517.

54. Compare carbon, tungsten, and nitrogen-tungsten incandescent lamps with reference to construction and efficiency in watts per cp.

55. Compare arc, flaming arc, and mercury arc lamps, with reference to construction and efficiency.

56. Compare the lamp efficiency (a) of a nitrogen-tungsten with that of a carbon filament lamp; (b) of the flaming arc with that of an open arc.

CHAPTER XI

ELECTROMAGNETIC INDUCTION

INDUCED ELECTROMOTIVE FORCE

497. Introductory. Practically all of our commercial electric currents today are obtained from dynamos by the process known as electromagnetic induction. The study of induced electromotive forces and induced currents is therefore of prime importance to the student of electrical phenomena. Oersted discovered that an electric current gives rise to a magnetic field about a conductor, and later on Faraday discovered that a changing magnetic field may give rise to a current. Faraday's famous experiment in electromagnetic induction may be repeated in any laboratory where there is available a coil of insulated wire, a galvanometer, and a magnet. If one end of a magnet (the N-pole, say) be thrust into a coil of insulated wire, the free ends of which are connected to a galvanometer, Fig. 526, the galvanometer needle will be deflected in a given direction; when the magnet is withdrawn from the coil, the needle will be deflected in the opposite direction. If instead of an N-pole an S-pole be used the respective deflections of the galvanometer needle will be in the opposite directions to those given by the thrusting in and pulling out of an N-pole. This is known in the literature of physics as Faraday's experiment in electromagnetic induction.



Michael Faraday

The current which flows through the coil and galvanometer when the magnet is being thrust in or pulled out is called an *induced current*, and the electromotive force developed by the

motion of the magnet is called an *induced electromotive force*. This induced e. m. f., and resulting induced current, is caused by the cutting of the lines of magnetic induction across the wires of the coil. It (the induced e. m. f.) manifests itself only when the magnet is in motion; that is, while there occurs a change (increase or decrease) of the lines of induction cutting across the coil. *The student should make special note of the fact that an induced current flows only while the magnet is in motion and the coil is closed.* If the coil be open while the magnet is in motion there will occur in the wire, as before, an induced e.m.f., but no current. Induced currents always occur as a result of induced electromotive forces.

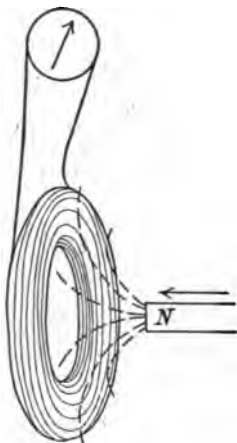


FIG. 526
Electromagnetic
induction

This experiment was first performed by Faraday in 1831. The relation of magnetism to electricity, as here shown, is known as the phenomenon of electromagnetic induction, upon which basis nearly

all modern electrical industries have been developed.

498. Relation of the Lines of Induction to the Induced E.M.F. We have seen, from the preceding experiment, that when lines of magnetic induction cut across a wire there is set up in the conductor an induced e.m.f. which, if the conductor be closed, gives rise to an induced current. We have also learned that when a current flows through a conductor, lines of magnetic induction are set up in the medium around the wire. That is, currents give rise to magnetic lines of induction, and, on the other hand, the motion of magnetic lines of induction may give rise to induced electromotive forces and induced currents. It is important, therefore, to know the relation which exists between the direction of motion of the lines of induction and the direction of the induced e.m.f.

There are two rules which are commonly employed to determine this relation as follows:

1. For the case of a circular conductor the following rule is serviceable. Consider that the N-pole of a magnet is thrust into a coil of wire, Fig. 527, and that the observer is in such

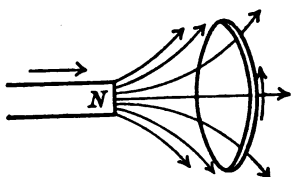


FIG. 527
Indirect induced e.m.f.

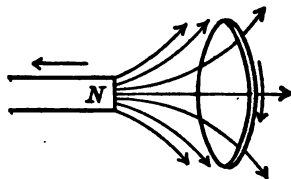


FIG. 528
Direct induced e.m.f.

a position as to look in the direction of the lines of induction, that is, from the S- to the N-pole, at the instant the magnet is thrust into the coil or withdrawn. When the N-pole is thrust into the coil there is an *increase* of the lines of induction threading through the coil which gives rise to an *indirect* induced e.m.f. as shown by the arrow in Fig. 527. When the N-pole is withdrawn there is a *decrease* of the lines of induction which give rise to a *direct* induced e.m.f., Fig. 528. The words indirect and direct as here used refer to the motion of the hands of a watch or clock. *Indirect* means *counter-clockwise*; *direct*, *clockwise*. This rule may easily be remembered if it be kept in mind that *i* stands for *increase* and also for *indirect*; likewise *d* stands for *decrease* and also for *direct*.

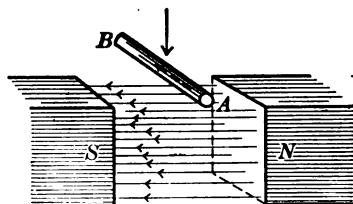


FIG. 529.—Induced e.m.f. in a rod cutting across a magnetic field

2. A second rule for determining the direction of the induced e.m.f. is as follows: Suppose that a conductor *AB* moves downward through a magnetic field, Fig. 529, cutting across the

lines of induction. The direction of the induced e.m.f. in the conductor is from A to B . Each line on being cut may be conceived of as tending to wrap itself around the conductor, as shown in Fig. 530. Now if we extend the right hand in

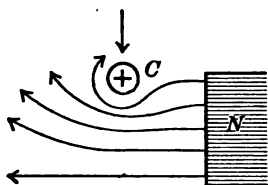


FIG. 530
"In" induced e.m.f.

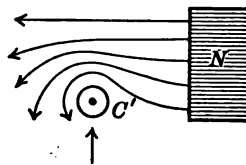


FIG. 531
"Out" induced e.m.f.

the magnetic field with the palm toward the moving conductor and the fingers in the direction of the lines of induction and thus grasp the conductor, AB , the thumb will point in the direction and sense of the induced e.m.f. If the conductor moves down then, as shown in Fig. 530, the induced e.m.f. is "in"; if the conductor moves up, Fig. 531, the induced e.m.f. is "out." The student will no doubt recall from Art. 460 that an *in* current or e.m.f. is represented by

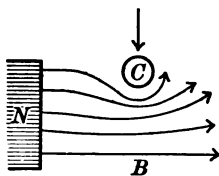


FIG. 532

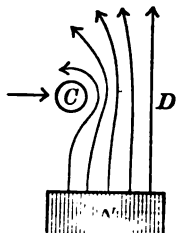


FIG. 533

the plus sign (+) and an *out* current or e.m.f. is represented by a point (•).

EXERCISES. 1. A conductor C , Fig. 532, moves in the magnetic field from C to B . Will the induced e.m.f. be directed toward or from the observer; that is, will it be *in* or *out*?

2. What will be the direction of the induced e.m.f. if the conductor of Fig. 533 move from *C* to *D*?

3. Find the direction of the induced e.m.f. when the conductor *C*, Fig. 534, moves in the direction (a) *C* to *A*; (b) *C* to *B*; (c) *C* to *F*; (d) *C* to *G*; (e) *D* to *E*.

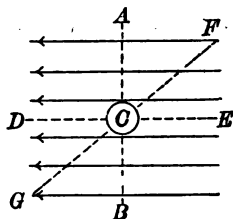


FIG. 534

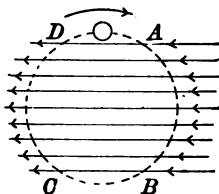


FIG. 535

4. The conductor shown in Fig. 535 moves through the magnetic field in a circular path in a clockwise sense. Find the direction of the induced e.m.f. when this conductor moves from (a) *A* to *B*; (b) *C* to *D*. (c) At what two places does the induced e.m.f. change its direction?

499. Value of the Induced E.M.F. The electromotive force induced in a circuit depends upon the number of lines cut per unit of time. Now the number of lines cut per second depends, in turn, upon three factors: (a) the number of lines in the field, (b) the number of conductors cutting the lines, and (c) the speed at which the cutting occurs. In the case of a magnet thrust into a coil, the number of lines cut per second will depend upon the pole strength of the magnet, the rate at which it is moved, and the number of turns of wire in the coil. It is therefore evident that if it is desired to design an apparatus which would give a maximum induced e.m.f., it will be necessary to provide for three things: first, a strong magnetic field; second, the use of as many turns of wire in the coil as will be practicable; and third, as high a rate of cutting of the lines as possible. This is practically the problem which presents itself in the designing of many pieces of electromagnetic apparatus, such as certain types of dynamos.

500. Self-Induction. Given a coil of wire connected to a battery, Fig. 536. When the key k is closed the current

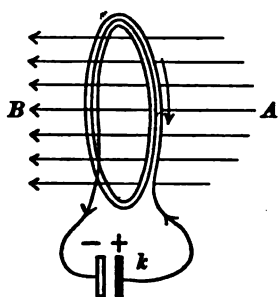


FIG. 536.—Counter e.m.f.

begins to flow around the coil in a clockwise sense, looking from A to B . The current in the coil, however, at once gives rise to magnetic lines of induction threading through the loop of wire in the direction from A to B . As the current increases the number of lines in the coil increases and there is produced in the coil an indirect induced e.m.f. which is opposed to the e.m.f. of the battery. That is to say, the appearance of these lines of induction in the coil has the same effect as would be observed if an N-pole of a magnet were thrust in from A to B . The e.m.f. due to the lines of induction in the coil is called the *counter electromotive force of self induction*; it tends to retard the growth of the current in the circuit. The counter e.m.f. of self-induction lasts only as long as the lines of induction continue to increase, that is, until the current reaches its maximum value. This explains why when a key is closed in a circuit containing a coil, the current rises to its maximum value slowly.

Now let us consider what happens when the circuit is broken. When the key k is opened the current dies down to zero, and as a consequence the lines of induction drop out of the coil. This decrease of the lines of induction produces a *direct induced electromotive force* which tends to prolong the current.

Thus it appears that when a current flowing through a coil is changing in value, that is, increasing or decreasing, there is present in the coil an e.m.f. of self-induction, which tends to oppose the increase of the current the instant the circuit is closed, and which likewise tends to prolong the current after the circuit is broken.

501. Lenz's Law. This opposition to change in an electromagnetic system is formulated by Lenz's law, which may be stated as follows: *When a change takes place in an electromagnetic system, that thing happens which tends to oppose the change.* Thus, by way of illustration, if we attempt to thrust a magnet into a coil, Fig. 537, there is developed in the coil, due to the induced current, poles which oppose the motion of the magnet; and likewise if we attempt to withdraw a magnet from a coil, a reverse induced current is produced which in turn gives rise to a magnetic field opposing the motion of the magnet. This all means that whenever we produce any change in the magnetic system, work has to be done in overcoming the opposing forces. Lenz's law has a very wide application in electromagnetics.

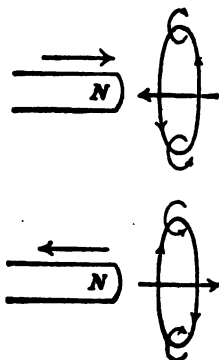


FIG. 537
Illustrating Lenz's law

THE DYNAMO AND ITS USE

502. Introductory. One of the most important pieces of electromagnetic apparatus is the *dynamo*, a machine designed for changing mechanical energy into electrical energy, or for changing electrical energy into mechanical energy. When a dynamo is used for the purpose of transforming mechanical energy into electrical energy it is called a *generator*; when it is used to transform electrical energy into mechanical energy it is called a *motor*. The fundamental principle governing the operation of the dynamo used as a generator is the production of an induced e.m.f. by the cutting of lines of induction; and when used as a motor, the production of mechanical motion due to the reaction of two magnetic fields.

503. The Simple Dynamo. Let us consider the dynamo as a generator. One of the simplest forms of generators is that

exemplified by a coil of insulated wire and a magnet, as shown in Fig. 526. When the magnet is thrust into the coil, lines of induction cut across the wires of the armature (coil) and a momentary current flows through the circuit; when the magnet is withdrawn the lines of induction cut across the conductors in the opposite direction and consequently a current flows through

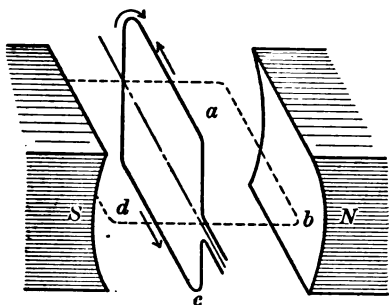


FIG. 538.—Ideal simple dynamo

the circuit in the opposite direction. Such a simple dynamo would give an alternating current; that is, a current flowing at one instant around the circuit in one direction and at the next instant in the opposite direction.

In the commercial dynamo, however, the cutting of the lines of induction may be accomplished not by moving the magnet, but by moving the coil or armature; that is, by the rotation of the armature about its axis in the magnetic field, as shown in Fig. 538. When the armature rotates in a clockwise sense through the arc *abc*, that is, makes one half revolution, the cutting of the lines of induction gives rise to an induced e.m.f. as indicated by the arrows; on the second half of the revolution, that is *cda*, the cutting of the lines of induction is reversed with respect to the conductors and the induced e.m.f. is in the opposite direction. Thus, starting with the armature coil in a vertical position, *ac*, the current, for the first half revolution, flows around the coil in one direction, and for the second half revolution, in the opposite direction. The current in the armature, then, is always an alternating current.

504. Terms Relating to the Dynamo. The magnets represented by *N* and *S*, Figs. 539 and 540, are called the *field magnets*, and the space between them is called the *magnetic field*.

The coil of wire which rotates in this field, is the *armature*. The two metal strips B and B' , which conduct the current from the armature, are the *brushes*. The conductor through which the current flows is the external circuit, or *main line*.

When the current is conducted from the armature to the brushes by means of separate rings, Fig. 539, one attached to each end of the wire of the armature, the dynamo delivers to

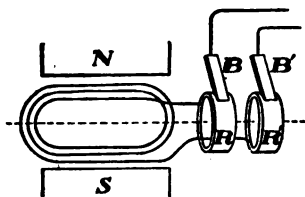


FIG. 539

Alternating and direct current dynamos

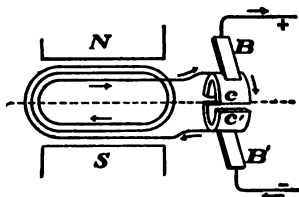


FIG. 540

the main line an *alternating current*, and it is therefore called an *alternating current dynamo*. The symbol for the term "alternating current" is A.C.

When the current is conveyed to the brushes by metallic segments, c and c' , Fig. 540, which device is called a *commutator*, the dynamo is called a *direct current dynamo*. The symbol for the term "direct current" is D.C. In the case of the D.C. generator the alternating current in the armature is changed or converted into a direct current in the line by the *commutator*, cc' . At the instant the current reverses in the rotating armature and the charges on c and c' change sign, segment c slips from brush B to B' , and in a like manner c' slips from B' to B . For this reason B remains positive, say, and B' negative.

505. Graphic Representation of Currents. It is sometimes desirable to represent graphically currents furnished by A.C. and D.C. generators. An alternating current is represented by the curve of Fig. 541 I , in which that portion of the curve above the line, abc , represents the current flowing in one direction, and the portion below the line, cde , represents the current

flowing in the opposite direction. This curve also shows the rise of the current as the armature rotates through the field. When the armature is passing through the positions *a*, *c*, and *e*, it is cutting a minimum number of lines of induction; hence the

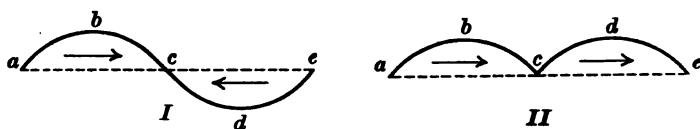


FIG. 541.—A. C. and D. C. curves

current has a minimum value. When the armature is passing through the positions *b* and *d*, it is cutting a maximum number of lines of induction and hence the current is a maximum.

The curve of Fig. 541 *II* represents what is called a direct current; that is, one which is furnished to the external circuit by the use of a commutator. It will be noted that all the loops of the curve lie on one side of the axis. This means that all the impulses of the current are in the same direction.

A direct current as furnished by a generator is not necessarily a continuous current, but rather a series of impulses in a given direction.

The current furnished by a battery of constant e.m.f. through a circuit of unchanging resistance is an example of a *continuous current*. Such a current is represented by the curve *abc*, Fig.



FIG. 542.—Curve representing a continuous current, as furnished by a battery

542, in which the part *ab* represents the rise of the current when the circuit is closed, and *bc* the continuous or unvarying current after it has reached its maximum value.

506. The Magnetic Field of a

Dynamo. In general, dynamos

depend for their magnetic induction upon the principle of the electromagnet. Indeed the poles of a dynamo are in reality nothing more than the poles of a big electromagnet. The manner of exciting this magnet depends upon the use to which the

dynamo is put. In the direct current generator there is usually enough residual magnetism in the poles to start at least a small current in the armature upon its rotation. All or part of this current is caused to flow around the field circuit, thus increasing the pole strength. In this way the dynamo is said to "build up" its magnetic field.

In alternating current dynamos this method of exciting the field cannot be directly employed, since the current in the external circuit is an alternating current. In A.C. generators, therefore, the field is excited from some outside source such as a battery or a small D.C. generator.

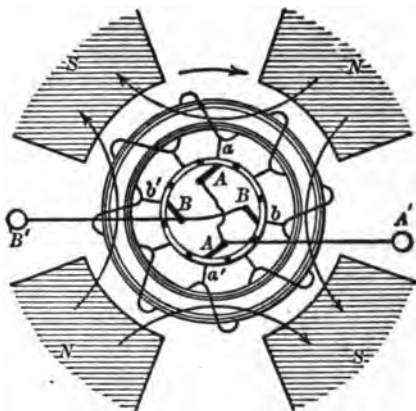


FIG. 543.—Diagram of four-pole dynamo

507. Kinds of Dynamos. Dynamos may be classified in various ways. (a) First, with reference to the currents fur-

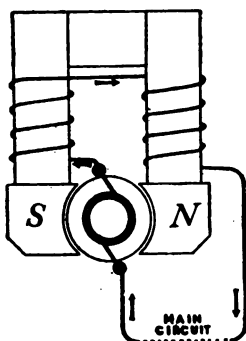


FIG. 544
Diagrams of series and shunt wound dynamos

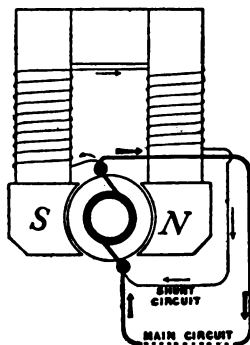


FIG. 545

nished or used, as A.C. or D.C.; (b) with reference to the number of field poles employed, as two-pole, four-pole, Fig. 543, or, multi-pole, some dynamos of the latter type having as many as 16 poles; and (c) with reference to field winding, as series wound and shunt wound.

In the *series* wound dynamo all the current of the main circuit passes around the field circuit, Fig. 544. In the *shunt* wound dynamo, on the other hand, only a portion of the current is carried around the field circuit, Fig. 545.

Current strength for any given system may be regulated by means of a rheostat. A rheostat is a frame or box containing

a series of conductors of relatively high resistance, connections with the various units being made by means of a movable contact, Fig. 546.

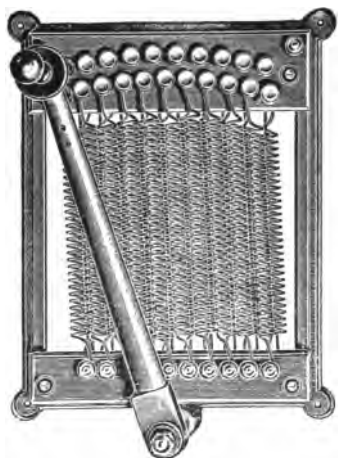


FIG. 546.—Rheostat

508. D.C. and A.C. Generators. Direct current generators are used on the secondary circuits of street electric lines to furnish direct currents to street cars; D.C. generators are also used for charging large storage batteries systems.

Generators of the A.C. type are now used almost universally for the generation of commercial currents, such as those employed in electric lighting, heating, and domestic motor service. The alternating current dynamo differs in principle from the direct dynamo, as already explained, in only two respects: (a) The armature of the machine is provided with rings instead of a commutator, as shown in Fig. 539, and (b) the field of the A.C. generator has to be excited by some outside source furnishing a continuous or direct current.

The *magneto* is an A.C. generator, the magnetic field of which is generated by permanent magnets of the horseshoe type, Fig. 547.

509. The Electric Motor. An *electric motor* is a device for transforming the energy of an electric current into the energy of mechanical motion. The principle of the motor does not differ from that of the generator, except that in one case the armature is rotated by mechanical means, thus generating a current; while in the other case a current is forced through the armature, causing it to rotate, due to a distortion of the magnetic field. Any ordinary D.C. generator, if connected up with a source of e.m.f., will operate as a motor; and on the other hand, any D.C. motor may be operated as a generator. For example, if an electric car be allowed to run down grade, its motor may act as a generator.

Motors are of two general types, with respect to the kind of current they are designed to take, namely, (a) D.C. motors and (b) A.C. motors.

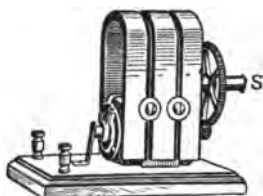


FIG. 547.—Magneto

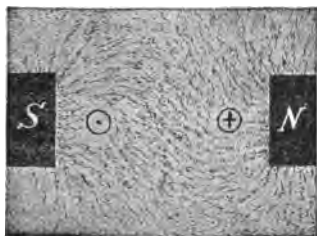


FIG. 548

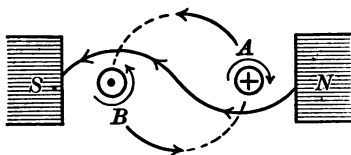


FIG. 549

Diagram of an electric motor

A direct current motor, like a D.C. generator, is provided with a commutator. As the current flows through the armature wires, lines of induction appear around each, thus distort-

ing the magnetic field. A photograph of such a distorted field is shown in Fig. 548. A wire was passed through two holes in a glass plate, in at *A*, then around and out at *B*. The plate was then placed upon the poles, *N* and *S*, of a magnet and iron filings sprinkled upon it. When no current flowed through the wire *AB*, lines of induction passed from *N* to *S* in relatively straight lines. When a current was passed through the wire, in at the right and out at the left, the lines of induction of the field were distorted, as shown. Now the tendency of these distorted magnetic lines is to straighten, thus causing the armature *AB* to rotate in a counter-clockwise sense, as shown in Fig. 547.

510. The Back E.M.F. in a Motor. When the armature of a motor rotates in a magnetic field, as explained in the preceding topic, it cuts some lines of induction and therefore tends to act as a generator. This gives rise to a counter or back e.m.f. in the armature, which opposes the applied e.m.f. at the brushes. *The faster a motor rotates, therefore, the greater is the back e.m.f. developed, and hence the less current it takes.* This fact may be demonstrated by means of a motor, in the circuit of which there is connected an ammeter, Fig. 550. When the current is turned

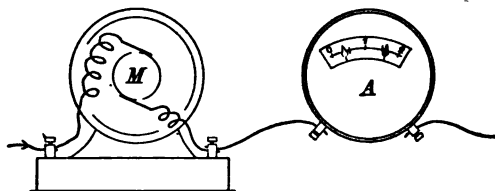


FIG. 550.—Back e.m.f. in a motor

on, the pointer of the ammeter gives a large throw, showing that a large current is flowing through it. As the motor speeds up, however, it develops a back e.m.f. which opposes the applied e.m.f. at the brushes, thus cutting down the current, as indicated by the fall of the pointer.

It is because of the fact that the current through the armature of a motor depends upon its speed that a "starting box," Fig.

551, is used in connection with motors of any considerable size. A *starting box* is a sort of rheostat so devised as to enable the operator by throwing a switch to reduce the resistance in the circuit and thus gradually increase the e.m.f. as the motor speeds up. If the full current were turned on while the motor is at rest the chances are that the initial current would be so great that the armature would be burned out. The motorman on the trolley cars uses a form of starting box which he operates in starting his car.

511. D.C. and A.C. Motors.

Direct current motors are used in propelling street cars, in automobile electric starters, and in certain kinds of shop work.

Since alternating currents are very extensively used now for domestic and public lighting, it is not always convenient or possible to make use of the D.C. motor. Alternating current motors are therefore commonly employed. Of the A.C. motors there are a number of different types, the one in most common use being known as the induction motor, a familiar example of which is seen in the small motor used to operate electric fans, sewing machines, vacuum cleaners, and similar household devices.

512. The Transformer. A *transformer* is a device for changing a current of high potential to one of low potential, or changing a current of low potential to one of high potential. The principle may be understood by considering Fig. 552. Suppose that an alternating current flows in the coil marked *P*, called the *primary*. The effect of this current in the primary is to magnetize the bar *B*. This will have the same effect as thrusting the magnet into the coil *S*, called the



FIG. 551.—Starting box

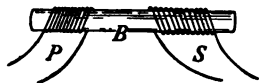


FIG. 552.—Bar transformer

secondary. Let us suppose that the effect on the secondary is the same as if an N-pole had been thrust into it. When the current reverses in the primary the polarity of the magnet is changed; that is to say, the N-pole becomes an S-pole. The effect of this change of polarity is the same as if the magnet were withdrawn, reversed with regard to its pole, and again thrust into the coil. Now it will be remembered that thrusting an N-pole into a coil gives rise to an indirect e.m.f.; withdrawing the magnet gives rise to a direct e.m.f. So, too, every time the current flows one way in the primary there is induced an e.m.f. in one direction, and every time the current reverses in the primary there is induced in the secondary an e.m.f. in the opposite direction. An alternating current in the primary

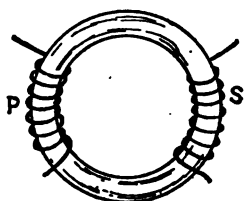


FIG. 553
Ring transformer

produces an alternating e.m.f. in the secondary, and therefore an alternating current, provided the secondary circuit is closed.

In Fig. 553 there is shown a form of transformer of the ring type. The coil of wire *P* is the primary and *S* the secondary. The relation between the e.m.f. of the primary and that of the secondary is determined by the relation of the number of turns of wire in the primary to the number of turns in the secondary. This relation may be expressed as follows:

E.M.F. of P: E.M.F. of S = No. turns primary: No. turns secondary.

Example. An alternating current having an e.m.f. of 2200 volts flows in the primary of a transformer having 200 turns in the primary coil and 10 in the secondary. Find the e.m.f. of the current in the secondary. *Solution:* $2200:x=200:10$; hence $x=110$ volts.

This means that by the use of such a transformer as described in this example a high tension current having an e.m.f. of 2200

volts may be "stepped down" to a current having an e.m.f. of 110 volts.

513. The Use of the Transformer. The transformer makes possible the transmission of electrical energy in the form of high potential alternating currents from a central power plant to points where the energy is to be used. By means of the transformer a current on the high tension wires may always be stepped down to a current of low potential. Small commercial transformers, as shown in Fig. 554, are often attached to electric lighting poles adjacent to dwellings. Their function is of course to step the high potential current down to one of low potential such as is safe to use in the lighting of houses, the running of domestic motors, and so forth.

The reason for using high tension currents on transmission lines is primarily one of economy in two respects. (a) When a very high e.m.f. is used very little attention has to be paid to the resistance of the line. The effect of high resistance can always be overcome by using a still higher e.m.f. We may therefore use relatively fine wire for the high transmission purposes, line resistance not being an important factor. The use of fine wires means a reduction in the expense of installing the system. (b) There is another reason also why a current of high voltage and low amperage is economical so far as transmission is concerned, and that is the fact that the heat loss for low current transmission is very much less than that for high current, since the heat generated in a conductor is proportional to the square of the current strength. We thus see that in high tension transmission we use wires through which flow currents of low amperage but of very high voltage. By means of a transformer a current of high voltage is

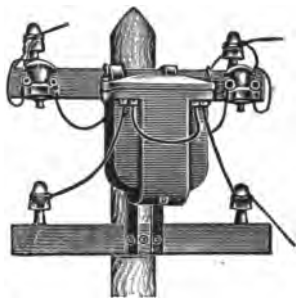


FIG. 554
Commercial transformer

stepped down to one of low voltage, and proportionally high amperage.

In the case of the transformer shown in Fig. 554, it should be noted that the wires carried by the upper cross piece of the pole are those of the high voltage circuit, while those attached to the lower cross bar are those of the low voltage circuit. The low voltage live wires are the ones which connect with the lighting systems of our dwelling houses, the current usually being under a pressure of 110 volts.

514. Avoiding Shocks from Electric Fixtures. While the current supplied is generally not considered dangerous to life under ordinary circumstances, nevertheless a certain degree of care should always be exercised in handling electric fixtures. Electricians when standing upon a dry floor think nothing of touching with their fingers a 110 volt or even a 220 volt circuit to ascertain whether or not it is "alive". On the other hand one should never touch the metal parts of an electric switch when the body is in contact with grounded lines, such as gas or water pipes. For example, one should never touch a switch while in a

bath tub, as the shock received by the moist body may prove serious, or even fatal.

Also, dangerous and many times fatal shocks sometimes occur from the touching of electric household fixtures due to the accidental crossing of high tension wires with those of the low tension circuit. How this may occur is shown in the accompanying

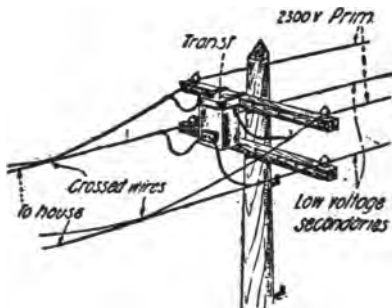


Fig. 555.—A dangerous condition: high tension primary wires crossed with low voltage circuit

illustration, Fig. 555. Here is shown a high tension line (2200 volts) which, due to storm conditions, has sagged and come

into contact with the low voltage circuit. Under this condition the fuses in the house will be blown as soon as the house circuit is closed; and further, the person who attempts to close a switch which is thus short-circuited with such a high tension wire, would be likely to receive a fatal charge. A number of cases are on record in which persons have lost their lives under conditions such as described.

A good point to keep in mind, therefore, is to exercise extreme caution in manipulating all lamp sockets or switches during or directly after a severe storm, which may have blown down high voltage wires so as to cause them to drop across low tension wires supplying house circuits.

ELECTROMAGNETIC APPLIANCES

515. The Electric Bell. The essential parts of an electric bell system are the battery, the push button, and the bell, as shown in Fig. 556. The push button, Fig. 557, is a device for making and breaking the circuit. The parts of an electric bell are shown in outline in Fig. 558. When the circuit is closed

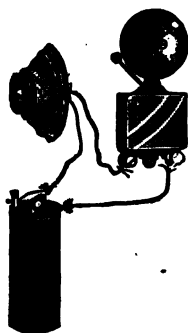


FIG. 556



FIG. 557
Push button

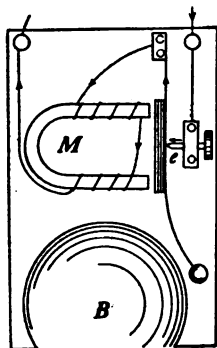


FIG. 558.—Diagram
of electric bell

by pressing the button the current from the battery magnetizes the iron core of the electromagnet *M*. This attracts the iron

strip or armature, causing a break in the circuit at *e*. As the armature moves downward it causes the clapper to strike the bell *B*. The moment the circuit is broken, however, the spring throws the armature back to the point *e*, thus again closing the circuit.

It is quite a common practice now to operate call bells on the commercial 110 volt A.C. circuit, thus doing away with the necessity of caring for the local battery. Bell systems of this sort are connected with the A.C. circuit by means of a small



FIG. 559
Bell and transformer designed
for A.C. circuits

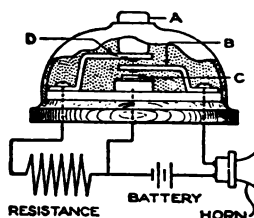


FIG. 560
Two-tone electric
automobile horn



FIG. 561
The first electric tele-
phone, as produced
by Alexander
Graham Bell

transformer. A bell designed to operate on an A.C. circuit is shown in Fig. 559, the small transformer in this case being attached directly to the bell.

516. Two-tone Electric Automobile Horn. In residential sections the loud blast from an electric automobile horn is an unnecessary nuisance, but on long stretches of country road, at sharp turns, or in crowded, noisy city streets a penetrating blast is often desirable. A push button designed to control the tone of the horn at the operator's will can be constructed easily, as indicated in the diagram. The usual push button *A*, Fig. 560, has two contact points and two spring-brass strips *B* and *D*. When the button *A* is pushed down a certain distance the battery circuit to the horn is closed through the high resistance. This furnishes a relatively weak current to the horn, and a low tone results. If now the button be pushed down farther, contact is made at *C*, thus closing the low resistance circuit. This gives a strong current to the horn and consequently there results a loud tone.

517. The Telephone. The electric telephone was invented by Alexander Graham Bell in 1875. In Fig. 561 there is shown the original crude telephone used by Bell in the first successful reproduction of speech electrically.

The characteristic features of a simple telephone are shown in Fig. 562. The working parts of a telephone system as outlined in Fig. 562 are the transmitter *T*, the receiver *R*, transformer *M*, local battery and the line *L*. The operation of the system may be briefly explained thus: When a person speaks into the transmitter *T*, the metallic diaphragm is set in vibration, pressing against the granulated carbon resistance *c*, and thus producing a variable resistance in the local circuit producing a variable current. This varying current produces an induced current in the line which affects the magnet of the receiver *R'*, the diaphragm of which is set in vibration. It is the vibrations of this diaphragm



Alexander Graham Bell

which produce the characteristic tones of the telephone. When a person speaks into the transmitter T' the same transmission of vibrations occur with respect to the receiver R .

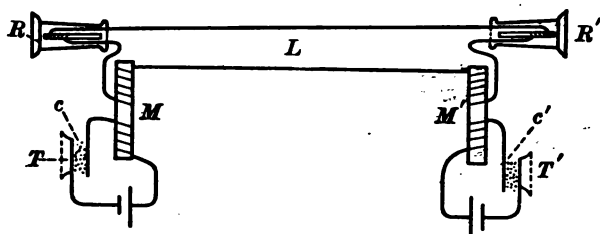


FIG. 562.—Diagram of simple telephone system

Of course the transmitter and receiver systems in modern telephone circuits are very much more complicated than those shown in Fig. 562; the principle upon which they operate, however, is not essentially different from that just explained. Sectional diagrams of the modern transmitter and receiver are shown in Fig. 563.

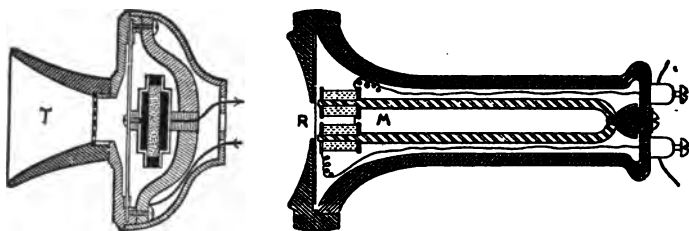


FIG. 563.—Modern transmitter and receiver

518. The Telegraph. The electric telegraph was invented by Samuel Morse in 1832. The operation of telegraphing from one point to another by means of the *key* and *sounder* system may be explained in connection with Fig. 564. The current from the battery at station A may be traced through the electromagnet m , the line L , the electromagnet m' , the battery at B , thence through the earth back to A .

Suppose now we wish to telegraph from *A* to *B*. The operator first opens his switch *s*. He now presses down key *k*, which

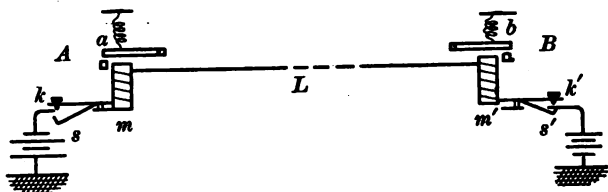


FIG. 564.—Diagram of simple telegraph

closes the circuit through the line to *B* and back through the earth. When the current passes through the two electromagnets *m* and *m'*, *a* and *b* are drawn down, giving rise to the clicking noise characteristic of the telegraph instrument. The combination of magnet and armature is called a *sounder*. Every time the key at *A* is pressed down there is produced in the sounder at both *A* and *B* corresponding long or short clicking intervals called *dots* and *dashes*. The operator at *B* reads the dots and dashes as they are sounded upon his instrument, and writes out the message. When the operator at *A* is through sending, he closes the switch *s*. This diagram above shows only two stations. In actual practice a great many stations may be on the line. The essential pieces of



Samuel B. Morse

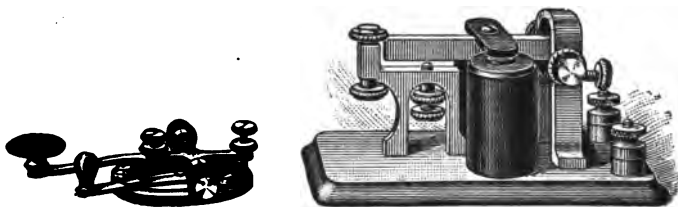


FIG. 565.—Telegraph key and sounder

apparatus in each station, however, are the key and the sounder, Fig. 565.

In Fig. 566 there is shown the Morse code, in which dots and dashes represent letters of the alphabet.

A — —	H — — — —	O — —	U — — —
B — — — —	I — —	P — — — —	V — — — —
C — — —	J — — — —	Q — — — —	W — — — —
D — — —	K — — —	R — — —	X — — — —
E —	L — — —	S — — —	Y — — — —
F — — —	M — — —	T — —	Z — — — —
G — — — —	N — —		

FIG. 566.—The Morse alphabet

519. The Induction Coil. An *induction coil* is an apparatus for producing high e.m.f. by the principle of electromagnetic induction. It is nothing more than a step-up transformer. The appearance of the ordinary laboratory coil is shown in Fig. 567, a diagram of this coil being given in Fig. 568. Surrounding the iron core are two coils of wire, the primary *P* and the secondary *S*. The primary coil which is wrapped directly around the core consists of a few turns of heavy insulated wire, which is

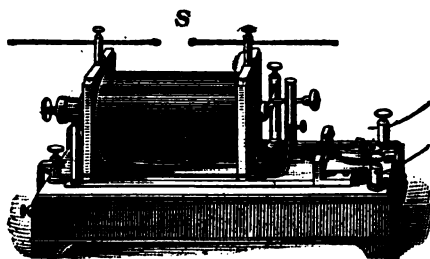


FIG. 567.—Induction coil

connected with the battery. The secondary wire consists of many turns of very fine wire, and is not connected in any way with the primary. Underneath the coil is a condenser *C*, which

consists of a number of sheets of tin foil carefully insulated from each other.

The operation of the coil is as follows: When the key is closed a current flows around the primary circuit, thus magnetizing the core, which in turn attracts the iron *a*. This breaks the primary circuit exactly as in the case of the electric bell. Now the effect of magnetizing and demagnetizing the core is exactly the same as if a magnet were thrust into the secondary and withdrawn again, thus inducing alternating currents. Since the induced e.m.f. in the secondary depends upon the number of lines of induction cut per second and the number of lines in turn depends upon the number of turns of wire in the secondary, the greater the number of turns in the secondary the greater will be the induced e.m.f. When the coil is in operation the hammer flies back and forth, making and breaking the primary circuit, thus magnetizing and demagnetizing the core. This produces an induced e.m.f. in the secondary which manifests itself in the stream of sparks across the terminals of the secondary. The induced e.m.f. of the secondary is usually determined

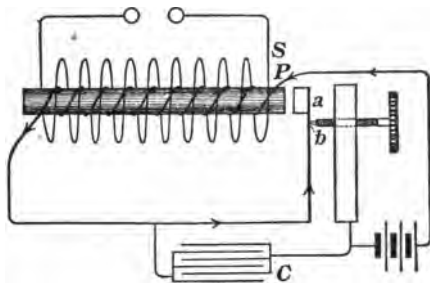


FIG. 568.—Diagram of an induction coil

by the length of spark which the apparatus will give in dry air between the spherical knobs of the secondary. To produce a spark one centimeter in length between spheres of one centimeter in diameter requires a potential of about 25,000 volts.

Induction coils have been made which are capable of giving a spark 50 centimeters in length. To do this would require a difference of potential between the knobs of the secondary of more than a million volts. It must be borne in mind, in this connection, that the induction coil does not enable us to increase the energy furnished by the primary circuit. While the e.m.f. of the secondary circuit is very high the current is proportionally small. Since the power of a current is equal to EI we see that if E be increased I will be decreased.

520. The Use of the Condenser. The *condenser C*, Fig. 568, consists of a series of layers of tin foil which are carefully insulated from each other and which are connected to the primary circuit on each side of the contact point b . The condenser may be said to have three uses in connection with an induction coil, as follows: (a) It prevents sparking at the point b . When the current flows around the primary circuit and the hammer a is drawn away from the point b a spark is produced. The production of a spark at this point is detrimental for two reasons: it tends to burn off the point, and in the second place it prevents a sudden breaking of the primary current. But when the condenser is in the primary circuit the energy of the primary current, instead of being expended in the formation of a spark, is expended in charging the condenser, one side becoming positively charged, the other negatively charged.

(b) Now while the hammer a is drawn to the magnet and the primary circuit is broken, the condenser, which the instant before was charged, now discharges itself back through the battery and around through the primary coil. This discharge from the condenser traverses the primary coil in the opposite direction to that which the current flows from the battery, suddenly cutting out the lines of induction in the core. This action of the condenser thus tends to demagnetize the core more rapidly than would otherwise be possible, thereby increasing the time rate of the cutting of lines of induction by the secondary, and consequently increasing the induced e.m.f.

(c) The third important function of the condenser grows out of this sudden interruption of the spark at the break. The current at "make" takes a fraction of a second to grow up to its maximum value; while at the "break" by the use of the condenser the cessation is almost instantaneous. Thus the rate of cutting of the magnetic lines of induction is much greater at the "break" than at the "make". The induced e.m.f. at the make lasts longer than at the break, but is feeble and does not suffice to send sparks across the gap. On the other hand, the induced e.m.f. at the break manifests itself by a brilliant torrent of sparks between the terminals of the secondary. Thus we may say that one function of the condenser is to produce a *unidirectional current* between the knobs of the secondary. This is important in certain kinds of experimentation, as, for example in X-ray work.

(d) When a condenser is not used in connection with the induction coil the discharge between the knobs of the secondary S is alternating. On large coils such as are frequently employed

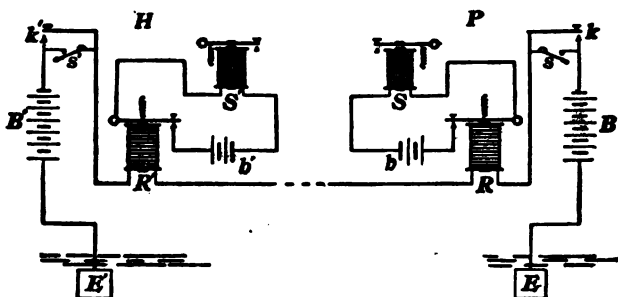


FIG. 569.—Diagram of commercial telegraph system

in wireless work the primary is operated by means of an alternating current from an A.C. generator.

521. Telegraph and Cable Lines. In commercial long distance telegraph systems currents from storage batteries or dynamos are used in the main line while in the local circuit voltaic cells, usually of the gravity battery type, are employed.

A diagram of a complete line and local telegraph system is shown in Fig. 569. Two stations are represented, one at *H* and one at *P*. When the resistance of the line is very high, the current is sometimes too weak to operate the sounder. To overcome this difficulty a local circuit consisting of the sounder and local battery is connected to the main circuit by means of a relay, *R*. The *relay* resembles the sounder in form. It con-

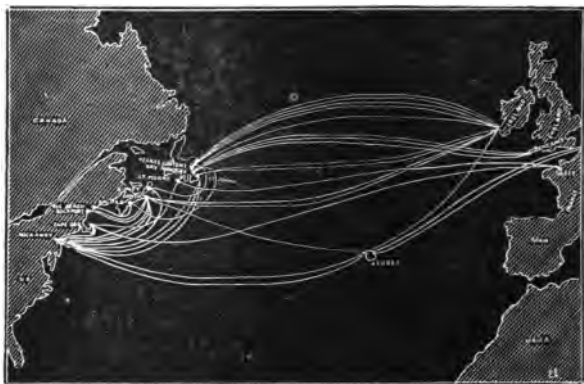


FIG. 570.—Cable systems connecting North America and Europe

sists of an electromagnet of many turns of fine wire and is designed to be operated by very weak currents. As the ~~signature~~ of the 'relay moves back and forth in response to the line current, it opens and closes the local switch, thus causing the local battery to operate the sounder.

International oceanic cables now connect all the continents of the world. The first trans-atlantic cable was laid by Cyrus W. Field in 1866, connecting Newfoundland with Ireland. Since that time many oceanic cables have been installed and are now in successful operation. A diagram of the Atlantic cables connecting North America with Europe is given in Fig. 570.

522. A. C. Rectifiers. An *electric rectifier* is a device for changing an alternating current to a direct current. There are a number of types of rectifiers among which are the following: (a) Mechanical rectifiers, (b) electrolytic rectifiers, (c) mercury arc rectifiers, (d) crystal rectifiers, and (e) vacuum valve rectifiers.

The *mechanical rectifier* has to be operated by mechanical power. The commutator on a D. C. dynamo is an example.

An *electrolytic rectifier* is a device for changing an alternating current to a direct current by the chemical action which takes place at certain

electrode substances in an electrolytic cell. For example it has been found that if one of the electrodes of an electrolytic cell consists of a plate of aluminum, this metal (aluminum) can act as a cathode but not as an anode. That is to say, if to an electrolytic cell having as an electrolyte a solution of sodium phosphate or even a solution of common borax, and electrodes consisting of plates of lead (Pb) and aluminum (Al), Fig. 571, there be applied an alternating e. m. f., a current will flow through the cell from the lead electrode to the aluminum electrode, but not from the aluminum to the lead. It is clear that a large part of the electrical energy applied to a rectifier of this sort is lost, so far as useful work is concerned. One disadvantage arising from the use of an electrolytic rectifier is that the cell heats up very rapidly when in operation.

The *mercury arc rectifier* is frequently used for charging storage batteries where only an alternating current is supplied by the electric power company. This rectifier consists of an exhausted-bulb *B*, containing two carbon or graphite electrodes marked *G*, Fig. 572, and a mercury electrode *M*. It is found that a current will pass through such a bulb only from the graphite to the mercury, but not in the reverse direction. In operating this device, the secondary terminals of an alternating current transformer *T* are connected to the graphite terminals of the rectifier. A wire connected to the center of the secondary of the transformer at *C* is attached to the negative terminal of the storage battery *SB*. The positive terminal of the battery is connected to the mercury electrode of the rectifier tube through a coil *R*, which by induction serves to sustain the arc between the alternations. The arc in *B* is started by means of a switch, not shown in the figure.

The *crystal rectifier*. Certain crys-

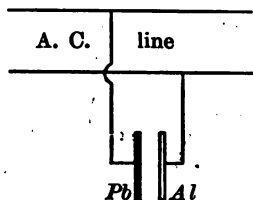


FIG. 571
Diagram of a lead-aluminum electrolytic rectifier

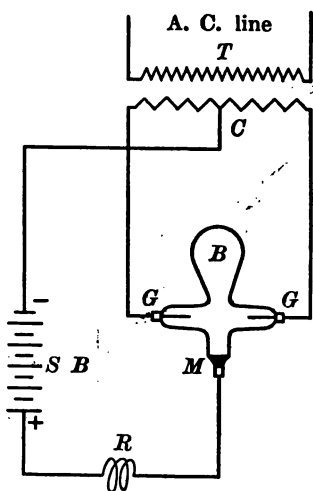


FIG. 572.—Diagram of a mercury arc rectifier

tals, especially those of carborundum, possess the property of transmitting a current in one direction but not in another. Because of this property such crystals have been used as detectors in wireless telegraphy, Art. 523. In modern practice, however, crystal detectors have largely been displaced by the more sensitive vacuum tube detectors.

The *vacuum tube rectifier*, sometimes called a *vacuum valve*, much resembles an incandescent lamp. But, besides the filament, it contains

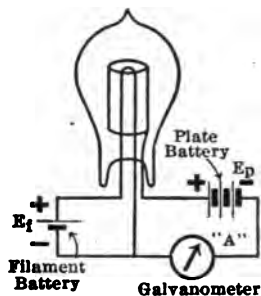


FIG. 573
Diagram illustrating the principle of Edison's vacuum valve discovery

a plate which sometimes takes the form of a metallic cylinder surrounding the filament. The discovery was made by Edison in 1883 that a current will flow in an evacuated bulb from the plate to the hot filament, but that it will not flow to any appreciable extent from the filament to the plate. In other words the metal plate and the hot filament in the evacuated bulb constitute a rectifier, allowing a current to flow in one direction but not in the other. The current between the plate and the hot filament is believed to be carried by electrons which stream off from the filament and impinge upon the plate. A fair understanding of the principle involved in Edison's vacuum valve discovery may be obtained from a study of Fig. 573. Here the battery E_f heats the filament, and the current between filament and plate is driven by battery E_p . This current is observed to flow when the plate is positive with respect to the filament even in the highest attainable vacuum, but it does not flow when the plate is negative. The presence of a current between the plate and the hot filament is demonstrated by means of a galvanometer.



Heinrich Hertz

Vacuum valves are used extensively today as rectifiers, and also as detectors in wireless telegraphy and telephony.

523. Wireless Telegraphy. In 1887 Hertz, a German physicist, discovered that electrical oscillations, such as occur on the discharge of a Leyden jar, give rise to electrical waves in the ether. Thus when the oscillatory discharge occurs between the knobs of an electric machine or between the terminals of an induction coil, electric waves are set up in the ether and travel

out in all directions from the source. These waves are capable of being reflected, refracted, and polarized the same as light waves; in fact the electric waves seem to possess all the properties of light waves, differing only in the fact that they are very much longer than those of light.

In order to detect these electrical waves, Hertz used a device called a spark-gap detector, Fig. 574. This consists of a rectangular wire C set up near the poles of an electric machine or induction coil. It was found that the size of the loop C could be so adjusted by means of the sliding wire S that when a spark passed between AB a smaller spark would appear at ab . That is to say, electric disturbances started at AB could be made to record their presence at ab . When the loop is in condition to give a spark at the knobs ab , it is said to be *in tune* with the discharging system AB .

This discovery by Hertz contained the fundamental principle of signaling through space by means of electric waves. The idea of the transmission of messages by means of electrical waves was later developed and

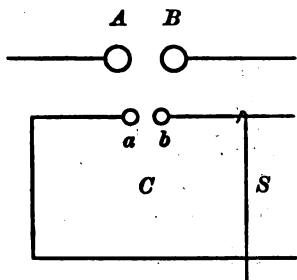


FIG. 574
The Hertz spark-gap detector



FIG. 575.—The coherer detector

perfected by Marconi, who invented the modern wireless system which in recent years has become of such great commercial importance.

When the spark passes between the knobs of an induction coil, a violent rush of electricity occurs, which may be accompanied by electric oscillations in any conductors connected with them. This electric surging gives rise to an electric disturbance which spreads out through space. Now when these electric waves reach a distant conductor they cause a somewhat corresponding disturbance in the conductor.



Marconi

In 1890 Branly and Lodge prepared a delicate detector for these electric disturbances, now known as Hertz waves. This detector is called a *coherer*, Fig. 575. It consists of a glass tube

loosely packed with metal filings. When the coherer is placed in an ordinary battery circuit it offers such a high resistance that scarcely any current will pass through it. It was discovered, however, that if an electric spark be produced in a near-by coil the filings in the tube at once conduct readily and continue to act as a good conductor until the tube is disturbed by tapping. The Italian physicist, Marconi, seized upon this discovery and after much experimentation devised an apparatus which would respond to the Hertz waves over a distance of hundreds of miles.

In the development of modern commercial wireless systems a variety of detectors were successfully used. These may be classified in order as (a) coherers, (b) magnetic detectors, (c) thermal detectors, (d) electrolytic detectors, (c) crystal detectors, and (f) vacuum tube detectors.

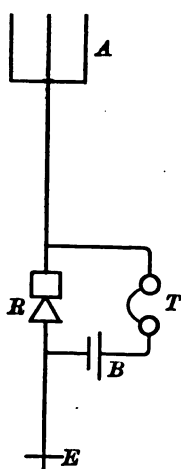


FIG. 576

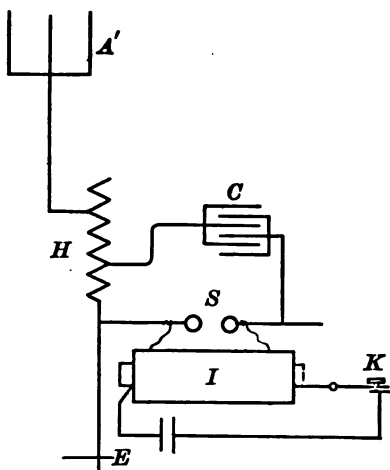


FIG. 577

Receiving and sending wireless systems

All of the earlier types have been displaced by crystal and vacuum tube detectors. Indeed, for commercial purposes the vacuum tube detectors are at the present time almost universally employed. Because of its convenience for illustrative purposes, however, we shall in this article speak of the crystal type of detector, reserving for a later article a discussion of the more sensitive vacuum tube detector known as the "audion."

In Fig. 576 there is shown a receiving system in which a crystal rectifier R is used. When electric oscillations are received by the antennae A , or receiving wire, the resistance at the contact point of the crystal appears to be changed, allowing a slight current from the battery to flow through the telephone, and thus giving rise to a crackling sound.

A sending station is represented in Fig. 577. The sending antennae are represented by A' . H is a helix which gives rise to self-induction, the adjustment of which, together with that of the capacity of the condenser C , enables the instrument to be tuned for long-distance transmission. I is an induction coil which is operated by means of the key K . S represents the spark-gap. When the key is operated, a series of brilliant discharges occur at S , giving rise to a series of oscillatory impulses which are communicated to the surrounding space. These electrical impulses are caught by the receiving antennae and the message read by means of the telephone, Fig. 578.

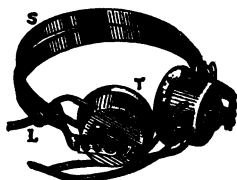


FIG. 578
Standard set of telephone receivers

524. The Audion and Wireless Telephony. The invention of the audion by Dr. Lee de Forest of Chicago made wireless telephony possible. The *audion* is an exceedingly sensitive vacuum tube detector, containing in addition to the usual filament and plate a "grid" which con-

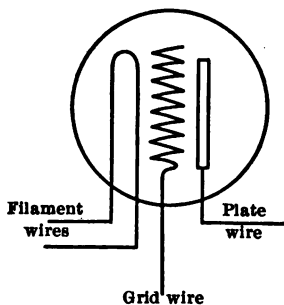


FIG. 579.—Audion and diagram of wiring system

sists of a zig-zag wire placed within the bulb between the filament and the plate, Fig. 579. De Forest found that by means of his audion the volume of the telephonic voice currents could be amplified as much as 20 times, so that loud telephonic speech could be obtained from voice

currents which were originally too faint to be heard distinctly. And further, it was found that when two or more audion bulbs are connected in the telephonic circuit, so that the amplified current of the



FIG. 580.—Receiving a wireless telephone message over a three-step audion system

first audion went to the second and to the third, the telephone transmitter became microphonic: that is, exceedingly faint sounds could be amplified several hundred to a thousand times in magnitude. In Fig. 580 there is shown a reproduction of a photograph of Dr. de Forest receiving a message over his three-step audion receiver.

By means of a system of amplifiers of the audion type it is now possible to telephone directly by wireless from the U. S. government radio station at Arlington, near Washington, D. C., to Honolulu and to Paris.

In Fig. 581 there is shown in outline the set-up of a modern radio receiving system containing an audion amplifier, and following, Fig. 582, government radio experts receiving a wireless message from an airplane.

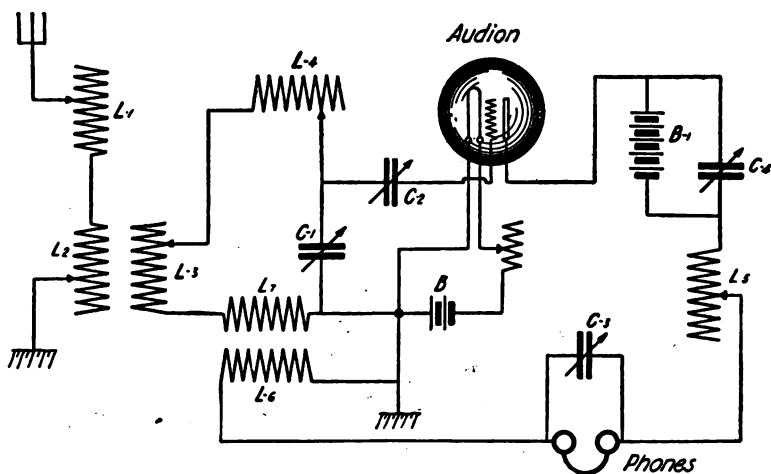


FIG. 581.—Diagram of a modern radio receiving station



FIG. 582.—Telephoning by wireless to an airplane

REVIEW EXERCISES

1. Describe Faraday's experiment in electromagnetic induction and name some of the practical applications resulting from this discovery.
2. Draw a circle on paper or on the blackboard and assume that the N-pole of a magnet is thrust into it. Indicate the direction (clockwise or counter clockwise) of the induced current when (a) the magnet is thrust in; (b) when the magnet is withdrawn.
3. What would be the direction of the induced currents in the foregoing case (exercise 2) if an S-pole were thrust in and then withdrawn?
4. The N-pole of a large magnet is pointing south. A person holding in his hands a conductor in a horizontal position faces the N-pole. What is the direction of the induced e.m.f. in the conductor (east or west) when (a) the conductor is moved downward through the magnetic fluid? (b) upward?
5. The lines of magnetic induction of the earth are assumed to be directed from south to north, entering the surface in the northern part of the United States at an angle of about 70° ; that is, they are nearly vertical. A railway train is in motion, the iron axles of its wheels cutting the lines of induction. What is the direction of the e.m.f. induced in an axle (a) when the train is moving north? (b) south?
6. At the magnetic equator the lines of induction of the earth's field are horizontal (north-south). At this place a ship with an iron mast is sailing west. What is the direction of the induced e.m.f. in the mast?
7. A magnet is fixed in a vertical position, its N-pole upward. A closed coil of wire is thrust downward over it. What is the direction of the induced current in the coil assuming that the observer is looking down upon it?
8. Name two ways in which a current may be induced in a closed coil.
9. (a) What is a dynamo? (b) a generator? (c) a motor?
10. Name the essential parts of a dynamo, and state the use of each.
11. What is the essential difference between a D. C. and an A. C. dynamo?
12. Make a sketch of a simple dynamo (generator) and explain the induced e.m.f. generated in the armature during one complete revolution.
13. A D. C. generator is delivering a current. Is the current in the armature direct or alternating? Explain.
14. (a) Upon what does the induced e.m.f. in a conductor depend? (b) In how many ways may it be increased?
15. By means of a sketch explain self induction in a coil of wire. Under what circumstances does this induced e.m.f. tend (a) to diminish the current in the coil? (b) increase it?

16. State and illustrate Lenz's law.
17. By means of sketches illustrate (a) an alternating current, (b) a direct current, (c) a continuous current. Explain the meaning of each part of each curve.
18. By means of a sketch explain why the armature of a motor rotates when a current flows through it.
19. What is meant by back e.m.f. in a motor? Explain what causes it.
20. As a motor speeds up does the current which it takes increase or decrease? Explain.
21. Explain why a starting box has to be used in connection with heavy motors.
22. By means of a sketch explain the characteristics (a) of a series dynamo, (b) a shunt dynamo.
23. A generator produces a current of 40 amperes at 110 volts. What is the power furnished (a) in watts? (b) kilowatts?
24. A motor takes 10 amperes at 220 volts. (a) What is the power applied in watts? (b) If the efficiency of this motor is 80 per cent how many horsepower of mechanical energy can it develop?
25. The efficiency of a motor used to run a washing machine is 85 per cent. (a) What electrical power must be applied in order to develop $\frac{1}{2}$ horsepower?
26. What will be the cost of running this motor (problem 25) for 2 hours if the cost of electricity is 10 cents per kilowatthour?
27. (a) What is a transformer, and for what is it used? (b) Are transformers used on D. C. or A. C. circuits?
28. In a given transformer the number of turns in the primary are to those in the secondary as 10 to 1. (a) Is this a step-up or a step-down transformer? (b) An e.m.f. of 1000 volts applied to the primary will give rise to what e.m.f. in the secondary?
29. If the current in the primary (problem 28) is 0.1 ampere what is the power applied to the transformer?
30. An induction coil has 200 turns in its primary and 60,000 in its secondary. A pressure of 10 volts is applied to the primary. What voltage will be induced in the secondary?
31. A transformer is used to step an alternating current having a pressure of 1000 volts down to one of 50 volts. If there are 500 turns of wire in the primary, how many will there be in the secondary?
32. A current of 5 amperes at a pressure of 110 volts passes through the primary of an induction coil, having 200 turns of wire in the primary and 2000 in the secondary. (a) What is the power applied to the primary? (b) the induced electromotive force?
33. The efficiency of a given transformer is 98 per cent. The power

applied to the primary is 270 watts. Find the power delivered to the secondary circuit.

34. By means of a sketch explain the operation of an electric bell.

35. Show the push button arrangement required to operate a two-tone electric horn.

36. Make a sketch of a simple telephone, and explain its operation.

37. A galvanometer is connected to the binding posts of a telephone receiver, Fig. 563. If the diaphragm of the receiver be pushed in slightly it will be observed that a momentary current flows through the galvanometer. Explain.

38. Make a sketch of a simple telegraph system, and explain.

39. What is a relay, and for what is it used?

40. Make a sketch of an induction coil, and explain the function (use) of each part.

41. What is an A. C. rectifier? Name some practical uses of a rectifier.

42. By means of a sketch explain Edison's discovery with reference to the vacuum tube rectifier.

43. Discuss Hertz's discovery of electrical waves, and explain by means of a sketch the device which he used to detect these waves.

44. Make a diagram of a simple wireless outfit. Explain the operation of both the transmitting and receiving systems.

45. What is an audion, and for what is it used?

CHAPTER XII

ELECTRICAL RADIATIONS

CATHODE RAYS AND X-RAYS

525. Introductory. We now come to a division of Physics which not very many years ago received but scant attention even in advanced text books, but which today is of enormous scientific interest to us and of much practical value as well. More investigations are probably being carried on at the present time in the field of electrical radiation and subjects relating thereto than in any other branch of physics. Not only has the whole subject of physics been profoundly affected by modern discoveries in this particular field, but the related sciences of chemistry and astronomy as well. Indeed one may say that the discovery of the electron and the properties associated with this new "ultimate electrical atom" has more profoundly affected our conception of the hidden mechanism of the physical universe than any other discovery since the days of Kepler and Newton. One has but to mention our modern notions as to the true nature of an electric current, the application of the X-ray in medical practice and in the arts, the amazing properties of radioactive substances, and the application of radium in the practical arts and sciences to indicate how wide is this new field and how significant to modern life are the subjects treated therein.

In treating the subjects of Electrical Radiations we shall in general follow the historical method, speaking in order of the Geissler tube, the Crookes tube, cathode rays, electrons, X-rays, and radioactivity.

By way of introduction, let us first consider what happens when an electrical discharge takes place in a sealed tube from which the air has been partly or almost wholly exhausted. In Fig. 583 we have represented a glass tube some two or three feet in length, and into the ends of which there have been sealed platinum electrodes, *a* and *c*. The auxiliary tube *T* leads to a high power air pump by means of which the air may be exhausted from the glass tube in successive steps. The electrodes *a* and *c* are connected to the terminals *A* and *C* of the secondary of a relatively high potential

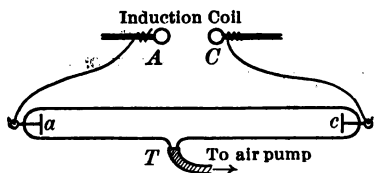


FIG. 583.—Electric discharge in an evacuated tube

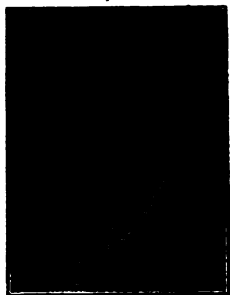
induction coil. Assume that *A* is the positive (+) and *B* the negative (−) terminal of the coil.

Let us suppose, to begin with, that the tube is filled with air, and the induction coil is closed. The following phenomena may be observed as the air is exhausted from the tube. (a) First, so long as the tube is filled with air no discharge between *a* and *c* occurs. Discharge, however, takes place between the knobs *A* and *C*, because the gap here is very much shorter than that between the electrodes *a c*. (b) Now start the air pump. In a few moments a discharge breaks across the gap from *a* to *c* in the tube, appearing as a ribbon of reddish light, which as the exhaustion continues, spreads out until the tube is filled with a diffused reddish light. At this stage the pressure of the air in the tube has been reduced to about 2 mm. (c) As the exhaustion continues, the color within the tube changes from red to green with intermittent dark spaces. The pressure in the tube is now about 0.5 mm. (d) And finally, as the exhaustion approaches that of a perfect vacuum the whole tube glows with a pale greenish color.

526. The Geissler Tube. *Geissler tubes* are glass tubes from which the air has been partially exhausted. Into the ends of the tubes there are sealed two short pieces of platinum wire which serve as electrodes. When these electrodes are attached to the poles of a static machine or to the terminals of an induction coil the tube becomes brilliantly lighted with colors which vary with the nature of the gas enclosed and with the kind of glass of which the tube is made. When the tube contains a trace of nitrogen the color given on discharge is violet; hydrogen, on the other hand, gives red. These tubes are often drawn into fantastic shapes, Fig. 584, which much enhance the beauty of their color effects.



FIG. 584.—Geissler tube



Sir William Crookes

Geissler tubes derive their name from Geissler, a German physicist, who invented a type of the mercury air pump, which he used in the exhaustion of these tubes. Geissler tube effects are obtained when the pressure is reduced to about 0.002 of an atmosphere, that is, 1.5 mm.

527. The Crookes Tube. The *Crookes tube*, named after Sir William Crookes, who was one of the first to work with it, is a tube from which the air has been thoroughly exhausted, the pressure being reduced to about

0.001 mm, or less. Crookes made an extensive study of the phenomena associated with electric discharge in evacuated tubes. He found, among other things, that not only does the color of the tube due to the discharge depend upon the degree of exhaustion, but also that the path of the discharge from the cathode (negative electrode) depends upon the degree to which the air has been removed.

Crookes tubes usually possess a bulblike form, as shown in Fig. 585.

528. Cathode Rays. *Cathode rays* are streams of negatively charged particles (electrons) which are shot off from the cathode in a Crookes tube upon the application of a high potential difference to the electrodes of the tube. These rays manifest themselves in various ways as follows: (a) *Fluorescent effect.* Cathode rays manifest themselves by the brilliant fluorescent effects which they produce in the walls of the tube

and in other substances within the tube upon which they fall. (b) *Heating effect.* The rays heat bodies upon which they fall. For example, if the rays from a cup shaped cathode in a tube be focused upon a piece of platinum foil the platinum will be heated white hot. (c) *Mechanical effect.* In the tube shown in Fig. 586 there is a light wheel having mica vanes and so adjusted as to roll on smooth glass rails. When a stream of rays is directed from the cathode so as to strike the upper vanes of the wheel it will rotate, rolling along the glass rails. When the current is reversed the direction of rotation of the wheel is reversed. (d) *Magnetic effect.* Cathode rays are deflected from their course by a magnet, as shown in Fig. 587. This is a very



FIG. 585
Crookes tube

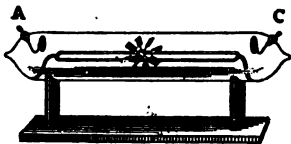


FIG. 586.—Mechanical effect
of cathode rays

significant phenomenon, because it tells us that a stream of cathode rays are of the same nature as an electric current.

529. Electrons. We have learned in our study of electrostatics (Art. 424) and again in the study of current electricity (Art. 429) something of the electron and its properties. It should be noted, however, that nearly all that is now known of electrons was learned by the study of electrical radiations within evacuated tubes. An investigation of the cathode rays led to the discovery of the electron. Cathode rays are nothing more than streams of electrons. An electron is a negatively charged particle. In exhausted tubes electrons may attain the enormous speed of 100,000

miles per second, that is, more than half the speed of light. Electrons are repelled by negatively charged bodies and attracted by positively charged bodies.

Much of our definite modern knowledge of electrons is due to the remarkable researches of Professor J. J. Thomson, of Cambridge University, England.

530. The X-Ray. *Roentgen* or *X-rays*, as they are sometimes called, were discovered by Roentgen, a German physicist, in 1895. When



FIG. 587.—Cathode rays deflected by magnet

cathode rays (streams of electrons) fall upon an object, as for example the metal reflector of a Crookes tube, Fig. 588, they give rise to X-rays, somewhat analogous to the manner in which a stone dropped into water gives rise to water waves. It is important to note that cathode rays are quite different from X-rays. The cathode ray is no more the X-ray than the stone is the water wave; one is the cause of the other.



Wilhelm Konrad
Roentgen

X-rays do not carry electrical charges, nor are they deflected by a magnet. X-rays consist of extremely short waves similar to but very much shorter than light waves. The wave length of ordinary yellow light is 0.0000589 cm; the wave length of the shortest X-rays is about one hundred millionth of a centimeter, that is, 0.00000001 cm, representing

a vibration rate of 3,000,000,000,000,000 per second.

531. Properties of X-Rays. Roentgen rays possess certain remarkable properties which may be stated briefly as follows: (a) Roentgen rays excite phosphorescence in a large number of substances. (b) Gases through which Roentgen rays pass become conductors of electricity. Thus if a charged electroscope be placed in the neighborhood of an active X-ray tube it will be observed that the gold leaves collapse, the charge of the instrument being rapidly carried away by the conducting air. (c)

These rays have great penetrating power, being able to pass through bodies of considerable thickness. Different substances absorb the rays in different degrees, as is well illustrated by the parts of the human body. The bones, for example, absorb the rays more strongly than do the fleshy parts. Metals also absorb the X-rays more strongly than do the non-metals, such as wood or paper. The penetrating power of Roentgen rays is determined largely by the pressure of the gas within the tube. High exhaustion gives rays of high penetrating power, known as "hard rays"; somewhat lower exhaustion gives rays of less penetrating power which are known as "soft rays."

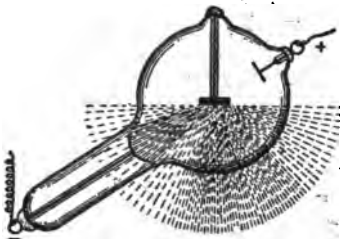


FIG. 588.—X-ray tube

Roentgen rays produce photographic action somewhat similar to that due to light, giving rise to the X-ray photograph or *radiograph*.

532. The Radiograph. The so-called X-ray photograph is really a shadow picture cast upon the photographic plate by the body through which the X-rays pass. The possibility of obtaining these radiographs

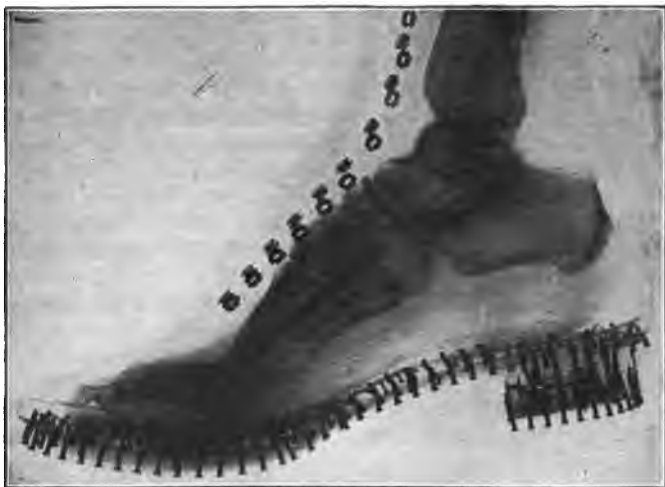


FIG. 589.—Radiograph

depends upon the absorbing power of different parts of the body to be photographed. The denser portions of the human body, for example, such as the bones, absorb the rays, thus giving a dark impression upon the picture. In Fig. 589 there is shown a radiograph of a foot enclosed within a heavy shoe, the bones of the foot and the iron nails of the shoe standing out very clearly.

533. The Fluoroscope. A fluoroscope is an apparatus which enables us to study the effects of X-rays without the use of photographic plates. It

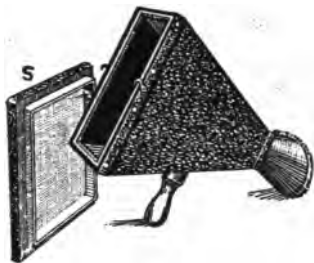


FIG. 590.—Fluoroscope

consists of a box as shown in Fig. 590, the small end of which is so constructed as to fit closely around the eyes. Over the large end is placed a fluorescent screen, made usually of platino-barium-cyanide. If an object, such as the hand, be placed between this screen and an X-ray tube the outlines of the denser portions of the object may be seen distinctly.

534. What X-Rays Show. The discovery of the X-ray was announced by Roentgen in 1895. The possibilities of the application of this new and wonderful agent in the domain of photography were at once recognized especially by those interested in medical science. Physicians and surgeons at once seized upon the X-ray as an aid in determining the location of broken bones and the extent and character of fractures in the human body. Naturally at first the methods employed were crude, but the technique of the X-ray work has rapidly improved until today roentgenology is a well established science in the field of medical diagnostic practice. Today the medical practitioner by means of the radiograph is not only able to locate a break or fracture in a bone or the position of dense foreign substances in the body, Fig. 591, but also he is able by means of the radiograph to study diseased conditions of the tissues such as abnormal growths within the body.

The modern dentist also has found that the X-ray is the only means whereby he can be sure that he is properly diagnosing certain ailments of his patient. Defective teeth are sometimes due to abscesses and other growths forming at the roots, which are not visible in any other way by physical examination, except by the X-ray. Such abscesses are the cause of serious organic and systemic disorders and ailments, such as rheumatism, neuralgia, stomach and intestinal troubles, and many other ills which would be difficult to determine definitely and to treat correctly without the helpful aid of the radiograph.

The X-ray is no longer confined to hospital and physicians' diagnostic requirements, but it has been used in the past few years, especially during the world war, for many hitherto undreamt of purposes. In fact, one could write a book on the industrial applications of X-rays which would

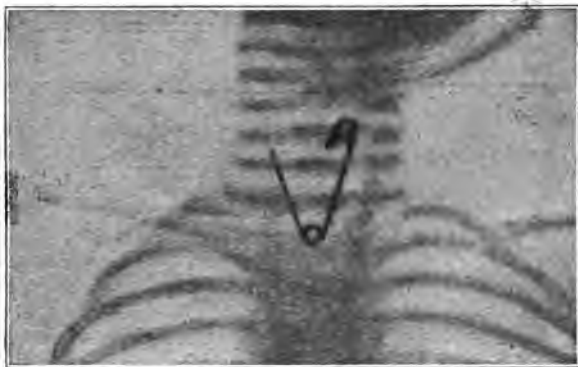


FIG. 591.—Radiograph revealing to the surgeon the location of a safety pin which was accidentally swallowed by a child

read like a romance. For example, during the war and after, great use was made of the X-ray in making detailed and critical studies of the physical condition of the materials which entered into the construction of airplanes. A single weak place in a brace or bar or in the engine of an airplane may mean the death of an aviator, and it is, therefore, necessary to examine critically every detail of the construction of aircraft. In Fig. 592 there is shown an X-ray operator examining the texture of a block of wood which it is proposed to use in the construction of an airplane. A large X-ray bulb is placed in the box below the block of wood and the operator is looking through a specially constructed fluoroscope.

Undoubtedly many railway accidents are caused by defects in rails and in the car wheels—defects which are invisible to the unaided eye. It frequently happens that car wheels which on ordinary inspection appear to be all right, and which withstand possibly a fair mechanical test, inherently possess a weakness, perhaps in the form of air pockets or invisible cracks caused by strains in cooling when they were cast, defects which only the X-ray can and does detect at once in a minimum of time. In Fig. 593 we have a striking illustration of this sort. In examinations of this character the X-ray tube together with the spark coil and batteries are

placed in a portable carrying case which can be placed behind the car wheel, rail, or shaft. The fluoroscope, or, in special places, the X-ray plate



FIG. 592.—X-ray expert examining a piece of wood designed for use in airplane construction



FIG. 593.—Radiograph showing flaws in a steel shaft designed for use in an airplane engine

in its light proof holder is placed before the object to be examined. A few seconds' exposure to the X-ray gives a photograph on the plate, which is afterward developed and printed, or the image may be and usually is ex-

amined on the negative itself, no print being made. Of course if the fluoroscope is used for directly viewing the object under examination, then the object is seen clearly at once, and various parts of it examined by moving the instrument over the surface.

During the war large X-ray machines were used to examine cotton bales prepared for export for hidden contraband rubber and nickel. Extensive



FIG. 594.—Radiograph reveals defects in war munitions

use also was made of X-rays in the examining of war munitions. In Fig. 594 there is reproduced a radiograph of a rifle shell which shows an imperfect distribution of the lead in the steel cap covering the top of the bullet.



FIG. 595.—Sealed package and contents, as revealed by the fluoroscope

Such a defect would be very likely to interfere with the true flight of the bullet.

Custom house officers often use the X-ray to examine the contents of imported packages, Fig. 595 showing such a package and what it contained, as revealed by the fluoroscope.

More romantic perhaps is the application of the X-ray for discovering the presence of pearls or the nuclei of pearls starting to grow in oysters. Previously many thousands of oysters were destroyed annually by being opened in an effort to determine the presence of pearls or pearl nuclei. All this is now obviated, thanks to the X-ray. If the oyster does not show up with a pearl nucleus it is replanted in the water once more. Here it develops to maturity. If an undeveloped pearl is detected by the X-ray pearl expert, then the oyster is at once laid aside for further treatment.

RADIOACTIVITY

535. Introductory. Nearly everyone nowadays has heard of radium and the remarkable properties which it possesses. The story of the discovery of this wonderful element is one of the most interesting in the annals of modern science. In 1896 Henri Becquerel, of Paris, accidentally discovered that the mineral uranium possessed the power of affecting a photographic plate. Following this discovery he wrapped a photographic plate in a piece of perfectly black paper, laid a coin on top of the paper, and suspended above the coin a small quantity of uranium. He then set the whole away in a dark room for several days. When he developed the photographic plate he found upon it a shadow picture of the coin similar to that produced by the Roentgen rays from an X-ray tube. He concluded, therefore, that uranium possesses the property of emitting rays of some sort which have the power of penetrating opaque objects and of affecting photographic plates, just as X-rays do. He found also, that these rays are like X-rays in that they discharge electrically charged bodies upon which they fall. Becquerel's discovery created a profound sensation among physicists and chemists, and at once stimulated a search for other substances besides uranium which might possess the property of emitting these new rays, which soon became known as Becquerel rays. A number of other such substances were found.

Any substance which spontaneously emits radiations like uranium is called *radioactive*, and it is said to possess the property of *radioactivity*.

536. Becquerel Rays. A study of radioactive substances revealed the fact that they not only emit rays which are capable of affecting a photographic plate, but also that such substances project from themselves electrically charged particles. In 1899 Professor Rutherford, then of McGill University, Canada, found that the Becquerel rays consist of three different kinds of radiations. These three types of radiations he named alpha, beta, and gamma rays, deriving these names from the first three letters of the Greek alphabet, namely, α (alpha) β (beta), and γ (gamma).

When Becquerel rays emitted from a radioactive substance were subjected to a strong magnetic field it was found that the gamma rays were unaffected, while the alpha rays were deflected in one direction and the beta rays in the opposite direction, Fig. 596.

The *alpha* rays possess relatively small penetrating power. They consist of positively charged particles having a mass which is calculated to be about 4 times that of the hydrogen atom and 7000 times that of the electron. Rutherford concluded that the particles of the alpha rays are positively charged atoms of *helium*.

The *beta* rays were found to be identical in all respects, with cathode rays; that is, the negatively charged particles of the beta rays are electrons.

The *gamma* rays, which are unaffected by a magnetic field are believed to consist of very short waves similar to those of the X-rays. In other words, they are waves in the ether like X-rays, only shorter. These rays are very penetrating and produce photographic effects.

537. Radium. Shortly after the discovery of the Becquerel rays Madame Curie, who was then working with her husband in one of the physical laboratories of Paris, began an investigation of all the known elements to find whether any of the rest of them possessed the remarkable property of radioactivity. She found that the element thorium, which is one of the chief constituents of Welsbach gas mantles, is capable together with its compounds of producing the same effect as uranium. In connection with this investigation Madame Curie noticed that pitchblende, the crude ore from which uranium is extracted, and which consists largely of uranium oxide, would discharge her electroscope about four times as fast as pure uranium. She inferred that the radioactivity of pitchblende could not be due solely to the uranium contained in it, and that this ore must therefore contain some unknown element which has the property of emitting Becquerel rays more powerfully than uranium or thorium.

After prolonged experimenting she obtained from several tons of pitchboard a few milligrams of a substance more than a million times as active as thorium or uranium. She called this new substance *radium*.

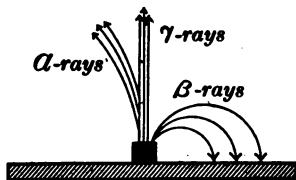


FIG. 596.—Alpha, beta and gamma rays



Madame Curie

As has just been stated, radium is more than a million times as radioactive as uranium, emitting alpha, beta, and gamma rays. Furthermore, radium is continually decomposing into other substances, this decomposition being accompanied by the evolution of heat.

538. Radium as a Medical and Chemical Agent. Radium is obtained as a chemical compound, usually as radium chloride or radium bromide. In this country, radium is obtained mainly from Colorado "carnotite" ore. From a whole ton of high grade Colorado carnotite ore we get only from five to seven milligrams of radium element. A thousand milligrams make one gram, and about twenty-eight grams make one ounce. There is in the entire world today only about three ounces of radium. It is valued at \$3,260,000 an ounce, while platinum the next most valuable mineral costs only \$150 an ounce.

Locked up in radium is one of the greatest forces that the world knows. Chemically it is very active, even being so powerful as to destroy living tissue and bone when brought for any length of time in contact with the body. An ounce of it carried in the vest pocket in an ordinary glass tube, would kill a man in ten hours by destroying his tissues and bones. If a man carried one gram of it in his pocket two days, serious results would likewise follow. The careless handling of glass tubes containing only twenty-five milligrams of radium will cause deep wounds on the fingers of an operator. Notwithstanding its great chemical activity, however, radium has been



FIG. 597.—Small dish containing \$120,000 worth of radium salt

successfully employed in medical practice in the treatment of certain diseases. Radium if carelessly handled will destroy tissues and bones, yet by the proper application under the direction of a medical expert it can be used so as to do no harm to healthy tissue, while destroying certain unhealthy tissues or malignant growths. It has been used to remove birthmarks and to reduce the scars inflicted on soldiers in the late war.

Undoubtedly in the future we shall learn much more of its value as an aid to the physician and the surgeon.

Figure 597 is a reproduction of a small silica bowl, resting upon the bottom of an inverted tumbler, containing one gram of radium element in the form of radium bromide salt, valued at \$120,000, and purchased by New York State for the Cancer Research Institute at Buffalo. This photograph was taken without the radium affecting the photographic plate, because the picture was made immediately after the evaporation of the radium salt, when it contains a minimum of its activity. After the radium is aged, that is, after it is one month old, the proximity of so great an amount would be dangerous, and a picture of it could not be made because the photographic plate would be burned. Radium salts are usually kept in small sealed glass tubes, which when not in use or when being transported from place to place are enclosed in a thick lead container, lead being relatively opaque to the radiations.

Radium is used to a limited extent at the present time in chemical laboratories to facilitate certain chemical reactions. For example, by the use of radium it is possible to produce in a small way in the laboratory nitrate compounds from the air similar to those existing in nature and known as Chili saltpeter, which is now used in enormous quantities in the manufacture of explosives and commercial fertilizers.

539. Radium as an Illuminating Agent. Radium offers interesting and attractive features as a commercial illuminating agent, and undoubtedly in the future when the production of radium salt from the natural ores has been developed on a much larger scale than at present radium illuminating paints will be used extensively.

One of the most familiar examples of radium illumination is that furnished by the modern "radiolite" watch, the hands and figures on the dial of which are so illuminated as to make it possible to tell the time in the dark, Fig. 598. When only a few millionths of a gram of radium is mixed with zinc sulphide, varnish, and certain other adhesive substances, it gives enough material to illuminate forty or fifty watches.

The use of radium for light has grown very rapidly in the past few years. Consider for instance the use of this substance in the illumination of hands and dials of time pieces. In 1913, two thousand watches and clocks, illuminated by radium, were manufactured in the United States.



FIG. 598
"Radiolite" watch

A few years later, during the war, one man out of every six in the U. S. army had a radium-lighted watch, and in 1920, 4,000,000 of these watches were made in the United States alone.

The commercial world was quick to see the many valuable uses that can be made of material which will glow in the dark. It was used on the dials of airplanes which flew over enemy camps at night, when exposure of light of another character would have made the airplane a target for shells. It was applied to speedometer, compass, clock, inclinometer, barometer,—altogether to fourteen dials used on airplanes.



FIG. 599.—Radiolite door plate and fixtures

Today, the dashboard instruments of automobiles, such as the speedometer, clock, and various gauges, tell the driver the condition of his car without the use of the electric light. Radium is practically the only means of illuminating motorcycle speedometers at night, since the motorcycle does not carry instrument lights. The steersman at the wheel of ocean going vessels can now be independent of artificial lights at night. Radium illumination is particularly good for these purposes, because when the eye has consulted a dial which is brightly lighted with electricity the vision is affected for a considerable period, so that the eye cannot look off into the dark with a normal degree of certainty.

Steam gauges, water-level glasses, and air-pressure gauges on locomotives and stationary engines are nowadays lighted with radium; so also is the pressure-

dial of the heater in the dark or semi-dark cellar of the modern dwelling. Radium lighted "Danger" signs and indicating arrows have been made for use in mines to protect miners from the danger of explosion of coal gas. Radium paint is also used for illuminating door plates and other entrance fixtures, as shown in Fig. 599.

Radium oil paints have recently been prepared for the use of artists in the painting of pictures. Pictures painted with radium oil look like any other picture in the day time, but at night they illuminate themselves and create an interesting and sometimes weirdly artistic effect. This paint is particularly adaptable for pictures of moonlight or winter scenes.

The time will doubtless come when it will be possible to have rooms lighted entirely by radium. It would be possible today to illuminate a room so that at night, without the aid of electricity or other artificial illumination, one could read fine newspaper print without difficulty. The light in such a room thrown off by radium paint on walls and ceiling would in color and tone be like soft moonlight, blue with a tint of yellow. Today, a room nine by ten feet could be illuminated in this way at a cost of about \$400, and the illumination would last ten years.

However, such illumination will soon be much cheaper than it is at present because of new discoveries which undoubtedly will be made as to the best materials to combine with radium to produce light.

REVIEW EXERCISES

1. Tell briefly what happens during the process of evacuating a tube, the electrodes of which are connected with the secondary of a closed induction coil circuit.
2. What is a Geissler tube, and what is the approximate pressure of the air within it?
3. Explain wherein a Crookes tube differs from a Geissler tube.
4. (a) What are cathode rays? (b) Of what are they composed? (c) From what electrodes do they emanate?
5. Discuss the properties of cathode rays with reference to (a) fluorescence, (b) heating effect, (c) mechanical effects, (d) magnetic effects.
6. (a) What is an electron? (b) What charge does it carry? (c) What is its relation to cathode rays?
7. (a) By means of a sketch describe an X-ray tube. (b) What are X-rays? (c) What is the relation of X-rays to light waves?
8. Name some of the properties of X-rays.
9. Describe the fluoroscope, and tell what it is used for.
10. State some of the practical applications of X-rays.
11. Describe Becquerel's discovery and define Becquerel rays.
12. Of what are Becquerel rays composed?
13. (a) What is the relation of gamma rays to X-rays? (b) What is the distinction between alpha rays and beta rays?

14. What is radium, and tell how it was discovered.
15. Discuss the use of radium as a medical and chemical agent.
16. Discuss radium as an illuminating agent.
17. What rays are given off by radium?
18. Explain why a tube containing radium discharges the leaves of an electroscope when brought near it?

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